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THE INFRARED ABSORPTION SPECTRA OF ACETYLENE, ETHYLENE AND ETHANE

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ABSTRACT

The spectra of acetylene, ethylene and ethane have been investigated with gratings in the region between 2 and 15μ. Each gas shows a more or less characteristic type of structure for its vibrational-rotational bands. The three main absorption regions of acetylene have been resolved into individual lines which are alternately intense and faint. These lines have the same average spacing in the three bands. The band at 13.7μ shows a strong unresolved Q branch, while the bands at 7.5 and 3.0μ lack evident Q branches. The two minor absorption regions of acetylene have also been investigated. The molecular moment of inertia has been computed from the spacing of the fine structure of the principal acetylene bands. The moment of inertia has also been computed from the classical theory on the assumption of a linear molecular model. The values obtained by the two methods are in agreement.

For ethylene, seven regions of absorption have been investigated. Two of these have been resolved into individual lines, with a strong Q branch present in one case and absent in the other. Four of the remaining regions reveal envelopes of an identical type, which is characterized by a sharp Q branch together with P and R branches. The bands found in the region of 2.3μ apparently lack Q branches. This latter group has been partially resolved.

The main absorption regions of ethane reveal bands, each consisting of a single succession of absorption maxima. The spacing of these maxima is different for each of the bands, but the structure obtained is for the most part of a regular nature.

INTRODUCTION

Our knowledge of the molecular structure of gases has been greatly advanced in recent years by the application of quantum mechanics to the vibrational-rotational bands in the infra-red region. The general shapes of the band envelopes, the presence or absence of Q branches, the frequency spacings and the relative intensities of the absorption lines are all questions to which theoretical interest is attached. The quantum mechanics has made considerable progress in the diatomic case, and its extension to the more general problem of the polyatomic molecule is engaging serious attention in the field of theoretical physics.

It was with the view of extending our knowledge of the fine structure of the infra-red bands and hence opening the way to their theoretical interpretation in terms of the quantum theory, that the present work was undertaken.

Preliminary investigations, reported in a previous paper,[1] were devoted to the absorption bands of several compounds in the region of 3.4μ. Of the many substances considered, the lower hydrocarbons offered the most promise of yielding relatively simple and resolvable fine structure. The scope of the present investigation has therefore been limited to the examination under high dispersion of the vibrational-rotational bands of acetylene (C_2H_2), ethylene (C_2H_4) and ethane (C_2H_6) in the spectral region from 2μ to 15μ.. Most of these bands have now been resolved and show fine structure having a regular nature. In some cases the regularities obtained are of a type not previously observed in vibrational-rotational bands.

The spectral region under consideration in the present work has been examined by Coblentz with a prism spectrometer. The results obtained in this manner for acetylene, ethylene, and ethane are included in his extensive treatise on infra-red absorption.[2] As a matter of convenience, the curves presented by Coblentz have been redrawn so as to show absorption increasing upwards, and are included herein as a part of Figure 1. The absorption regions for acetylene have been re-explored with a prism spectrometer by Burmeister[3] whose readings extended as far as 22μ. No indications of absorption were reported for the region beyond 15μ, but at 2.5μ Burmeister located a minor absorption maximum which did not appear in Coblentz' curves.

All of the absorption regions for the three gases have been examined under high dispersion in the present investigation, with the exception of the minor absorption maximum for ethylene at 4.3μ. Investigation of this maximum was unfeasible, because of the strong overlying absorption of carbon dioxide in the atmosphere.

From a comparison of the frequencies of the absorption maxima for acetylene and ethylene as given by Burmeister and Coblentz respectively, Hettner[4] has suggested that certain of the bands might be explained as harmonics of a fundamental vibration frequency. Such

[1] Meyer, C. F., Bronk, D. W. and Levin, A., J.O.S.A. & R.S.I. *15*, pp. 257–266; 1927.

[2] Coblentz, W. W., Publications of the Carnegie Institution of Washington, *35;* 1905.

[3] Burmeister, W., Verhandlungen der Deutschen Physikalischen Gesellschaft, *15*, pp. 589–612; 1913.

[4] Hettner, G., ZS. für Physik, *1*, pp. 345–354; 1920.

an assumption is quite logical on the basis of the prism data alone. The examination of the bands under high dispersion, however, reveals important differences in the structure of the so-called fundamental and harmonics which make such a classification exceedingly doubtful.

APPARATUS

The grating spectrometer used in this work is of a type similar to that employed by previous investigators,[5] and therefore will not be described here in detail. Modifications of an important nature, however, lead to a high degree of sensitivity of the recording apparatus and hence allow investigation with a grating to a greater wave-length than has been previously reached. As a further consequence of the increased sensitivity, it has been possible to reduce the slit widths considerably and thus obtain improved definition. In the following discussion, only the important features of the apparatus will be considered.

The radiant energy from a Nernst glower is passed through a fore-prism of rock salt which serves as a monochromator. This prism is necessary in order to prevent the overlapping of spectral orders. The energy passes from the monochromator through the absorption cell containing the gas to be studied, and then falls upon the slit of the spectrometer. The focal length of the spectrometer is 100 centimeters. The gratings used are all large Michigan echelettes, ruled by Dr. Barker. A grating ruled with 7200 lines per inch (2834 lines per cm) on a copper-nickel surface was found to be most effective for the region between 2μ and 4μ. From 4μ out to the neighborhood of 8μ, the best results were obtained with a grating having 2880 lines per inch (1134 lines per cm) on an aluminum surface. The region from 8μ to 15μ was made accessible by a grating of 1440 lines per inch (567 lines per cm) ruled on a tin surface.

The detecting system consists of a vacuum thermocouple, a Moll thermal relay and a Leeds and Northrup high-sensitivity galvanometer of the D'Arsonval type. The vacuum thermocouple was constructed according to the method of Dr. A. H. Pfund[6] and was furnished with a calcium evacuator.[7]

The absorption cell is equipped with rock salt windows and can be used effectively throughout the entire spectral region from 2μ to 15μ. Compensating windows were found to be unnecessary, as the diminution

[5] Sleator, W. W., Astrophysical Journal, *48*, pp. 125-143; 1918.
[6] Pfund, A. H. Physikalische ZS., *13*, pp. 870—873; 1912.
[7] Coblentz, W. W. J.O.S.A. & R.S.I., *5*, pp. 356—362; 1921.

of energy due to the rock salt windows can be satisfactorily taken into account. The length of the absorption cell can be varied from 1 mm to 20 cm.

Between 2μ and 3μ, the dispersion of the rock salt prism was found to be too low to eliminate overlapping of the spectral orders. Consequently an asphaltum filter was used for work in this region. This filter is practically opaque to energy as far as 1.5μ, while it transmits a major portion of the energy from 2μ to 3μ. Hence it serves its purpose quite admirably.

EXPERIMENTAL PROCEDURE

The absorption cell was adjusted to a convenient length and sealed. Thereupon it was filled with the gas which had been passed through a drying chamber containing concentrated sulphuric acid. For a majority of the runs the length of the cell was 8 centimeters. When working in regions of intense absorption, the effective gas content of the cell was decreased to a suitable value by diluting with air.

The percentage of absorption due to the gas at any given position of the grating was obtained from repeated galvanometer deflections which were observed on opening and closing the shutter with the cell in the beam and with the cell out of the beam. In investigating a region of absorption, an exploratory run was first taken point by point, the successive positions of the grating being separated by intervals of five minutes of arc. This preliminary run was carried well beyond the limits of the region as shown by the prism curves of Coblentz. The main absorption region thus determined was then examined more fully with narrower slits and at smaller intervals.

The calibration of the 7200 line grating was based upon repeated observations on the -3 and -4 lines of hydrogen chloride, whose positions have been determined by Colby, Meyer and Bronk.[8] These same standards served for calibrating the 2880 line grating, but in this case the calibration was supplemented by visual observations on the green mercury line. The 1440 line grating was calibrated from the first and second order images of the sharp Q branch of ethylene at 5.292μ, as previously obtained with the 2880 line grating. The latter calibrations were confirmed by some direct measurements made by Dr. Barker on the comparator.

[8] Colby, W. F., Meyer, C. F. and Bronk, D. W. Astrophysical Journal, *57*, pp. 7—19: 1923.

DISCUSSION OF RESULTS

An assembly of the results is presented in Fig. 1. In this are included the prism curves obtained by Coblentz, and associated with each region of absorption is a miniature graph showing the nature of the fine structure revealed in the present work.

A typical curve for each region investigated is shown in the figures numbered 2 to 13. These curves were originally plotted with absorption percentages as ordinates and with settings of the spectrometer circle as abscissae. The scale of circle settings has, however, been replaced in the figures by corresponding scales of wave-lengths, in μ, and of wave-numbers per millimeter.

For purposes of reference, arbitrary numbers are assigned to the individual lines in the absorption bands. Each line which has been confirmed by repeated observations is given a number. This number is indicated by a scale placed slightly below the curve in each figure. Scale marks have also been placed beneath some of the minor maxima which have not been confirmed, and which may be due to observational error. Moreover, scale marks have occasionally been inserted where there are no maxima at all; this has been done either for convenience in making out the scale, or to allow numbers for lines which may be disclosed by future investigation. In determining line numbers, the reader should take account of the number of marks between adjacent numbered positions of the scale; e.g. in Fig. 11, there are four marks between Nos. 270 and 280. The absorption lines above these marks consequently carry the numbers 272, 274, 276, and 278. There is no mark corresponding to line No. 277, but it is readily ascertained to be the faint line lying between lines 276 and 278.

Numbers are also assigned to the maxima of the envelopes of the P, Q, and R branches. These maxima cannot be located with a high degree of precision. Consequently for the branches which have been resolved into lines, the maximum of the envelope may with sufficient accuracy be taken as coincident in position with one of the lines. When a branch is not resolved into lines, the plotted observations yield directly the envelope of the branch, and a number is assigned to the maximum of the plotted envelope.

Table 1 gives information regarding the experimental conditions under which the absorption curves were obtained. It may be noted that the slit width, expressed in spectral range, varies from 164A to 8A. In regions where the amount of energy available permitted the use of narrow slits, a high order of definition was attained.

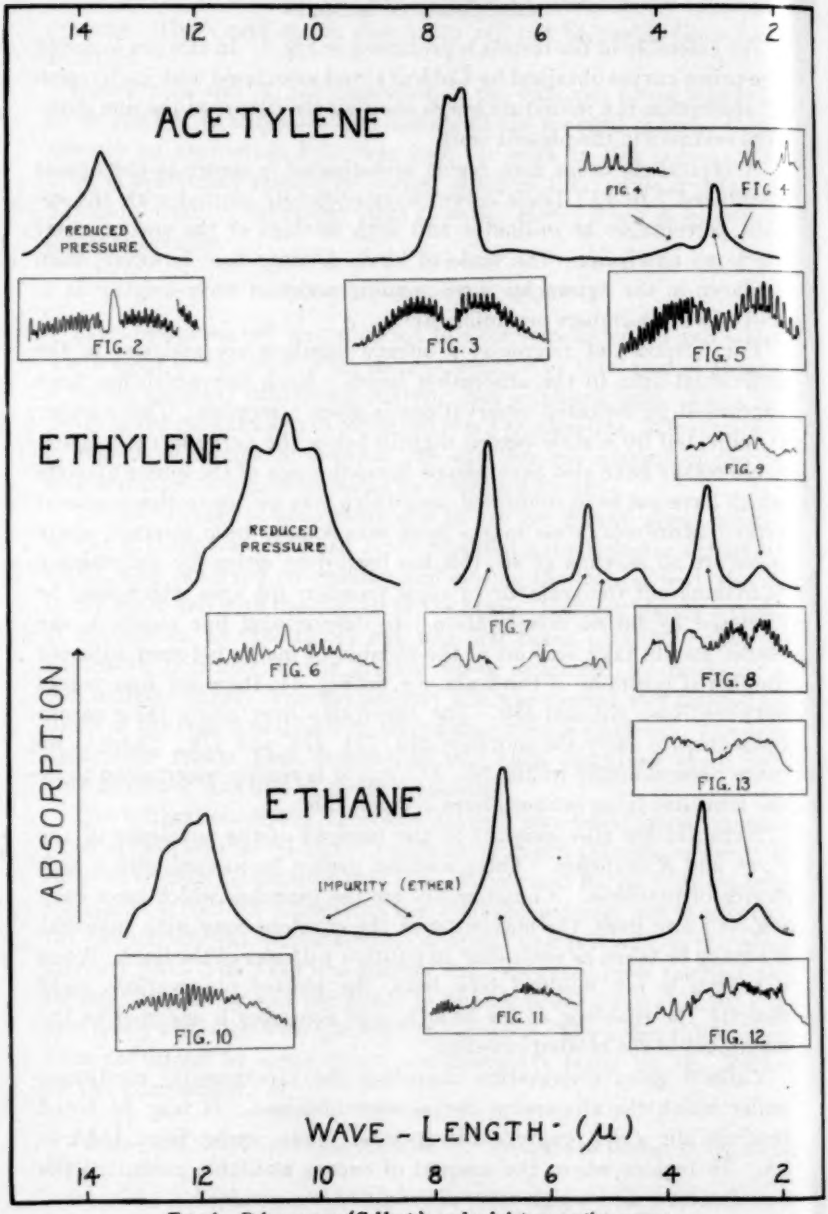

FIG. 1. *Prism curves (Coblentz), and miniature grating curves.*

TABLE 1. *General information regarding conditions under which following tabular data were obtained.*

Gas	Region	Grating Lines/cm	Interval of readings		Slit width		Cell length, cm
			Min.	A. U.	mm	A. U.	
Acetylene	13.7μ	567	1	94	1.00	160	4 Partly Filled
	7.5	1134	1	46	0.75	59	8 " "
	3.7	2835	1	17	0.50	15	8 Filled
	3.0	2835	1/4	5	0.25	8	8 Partly Filled
Ethylene	10.5μ	567	1	98	0.80	134	8 Partly Filled
	6.9	1134	1/2	23	0.75	60	6 " "
	5.2	1134	1	49	0.50	42	8 " "
	4.9	1134	1	49	0.50	42	8 Filled
	3.3	2835	1	18	0.50	16	8 Partly Filled
	2.3	2835	1	19	0.50	16	8 Filled
	Lines 656–676	2835	1/2	10	0.25	8	8 Filled
Ethane	12.2μ	567	1	96	1.00	164	3.2 Filled
					0.50	82	3.2 "
	7.5	1134	1	46	0.75	59	8 Partly Filled
	6.8	1134	1	47	0.75	60	8 " "
	3.4	2835	1/2	9	0.50	16	8 " "
	2.4	2835	1	19	0.50	16	8 Filled

The following tables numbered 2 to 12, give the wave-numbers of the absorption lines and the wave-number differences between adjacent lines. The wave-numbers corresponding to minor maxima in the curves are included in the tables only when these minor maxima have been confirmed by repetition. The table numbers have been made to correspond throughout with the figure numbers, so that the data for any given region of absorption may be found under the same number in both tabular and graphical form. The results obtained for each of the three gases investigated will now be presented in detail.

ACETYLENE

The acetylene gas was obtained from a Prest-o-lite cylinder, and was dried by passing through concentrated sulphuric acid. The principal regions exhibit very regular structure and evidently contain no lines due to impurity in the gas.

The prisms curves of Coblentz show three main absorption regions. Each region has been examined and its fine structure revealed. The structure obtained is remarkably simple and regular, in view of the

TABLE 2. *Acetylene—Region of 13.7μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
130	684.71		141	710.44		155	741.08		166	766.96	
		2.16			2.30			2.53			2.15
1	6.87		2	2.74		6	3.61		7	9.11	
		2.40			2.57			2.05			2.42
2	9.27		3	5.31		7	5.66		8	771.53	
		2.41			1.93			2.42			2.46
3	691.68		4	7.24		8	8.08		9	3.99	
		2.22			2.68			2.28			2.12
4	3.90		5	9.92		9	750.36		170	6.11	
		2.18			2.21			2.28			2.49
5	6.08		6	722.13		160	2.64		1	8.60	
		2.54			2.47			2.70			2.13
6	8.62		7	4.60		1	5.34		2	780.73	
		2.42			1.52			2.25			2.40
7	701.04		8	6.12		2	7.59		3	3.13	
		2.30						2.20			2.30
8	3.34		150	730.35		3	9.79		4	5.43	
		2.31						2.35			2.48
9	5.65		2	3.61		4	762.14		5	7.91	
		2.37			2.72			2.50			2.07
140	8.02		3	6.33		5	4.64		6	9.98	
		2.42			2.29			2.32			
			4	8.62							
					2.46						

	Coinciding with line no.	Wave number ν(cm⁻¹)	Δν
Maximum of Envelope, P Branch	140	708.02	
			22.33
" " " Q "	150	730.35	
			22.29
" " " R "	160	752.64	

complexity of the acetylene molecule, and there is great promise that it will lend itself to theoretical treatment. The two minor absorption

maxima located by Burmeister at 3.8μ and 2.5μ have also been further resolved.

Region of 13.7μ (Fig. 2, Table 2): The wide and intense absorption maximum shown by the prism curve resolves itself into a band consisting of P, Q, and R branches. The P and R branches consist of two sets of absorption lines of alternately high and low intensity, this alternation being most strongly marked in the R branch on the right of the figure. The detached portion of curve shown here represents observations taken with more gas in the cell.

In the P branch the alternation of intensities is again well marked in lines 130 to 142. Perturbations in the spacing and intensity of lines numbered 143 to 146 were at first attributed to experimental error.

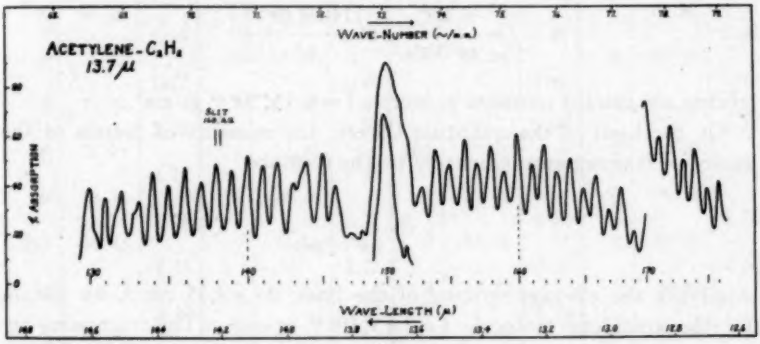

FIG. 2.

Repeated observations over this region, however, have confirmed the perturbations shown. The irregularities which are apparent at the left end of the P branch can, on the other hand, be attributed to observational error. The energy falls off very rapidly in this region due to absorption by the carbon dioxide of the atmosphere.

There is no convergence in either the P or the R branch, the average spacing of the lines being 2.35 cm^{-1}. The small deviations from this value shown in the table are due to experimental error in locating the positions of individual lines. If the above value of the average spacing is applied to the central portion of the band, it is apparent that there are just nine spacings between lines 145 and 155. Due to the absence of convergence in the band, this determination can be definitely made. Hence it is seen that the strong lines in the R branch form a regular sequence with the weak lines in the P branch, and vice versa.

Repeated runs taken over the Q branch with decreasing gas content show a progressive shift of the branch toward lower wave-numbers. This indicates that the series of lines constituting the Q branch is degraded toward higher wave-numbers.

An attempt has been made to set forth the three positions of maximum absorption in the envelope of the band. These positions are of importance as they lead directly to values of $\bar{\nu}_r$, the "most probable frequency of rotation" which enters into classical theory. An exact determination is difficult, particularly for the P branch due to the flatness of its envelope. The mean value of 22.3 cm^{-1}, representing the authors' determination of $\bar{\nu}_r$, can be applied in the classical formula[9] for a linear molecular model,

$$I = \frac{RT}{4\pi^2 N c^2 \bar{\nu}_r^2} = \frac{1140 \times 10^{-39}}{\bar{\nu}_r^2},$$

giving a resultant moment of inertia $I = 2.3 \times 10^{-39}$ gr-cm^2.

On the basis of the quantum theory, the moment of inertia of the molecule is given approximately by the formula

$$I = \frac{h}{4\pi^2 c(\Delta\nu)}.$$

Applying the average spacing of the lines, $\Delta\nu = 2.35$ cm^{-1}, we obtain for the acetylene molecule $I = 2.4 \times 10^{-39}$ gr-cm^2. This compares re-

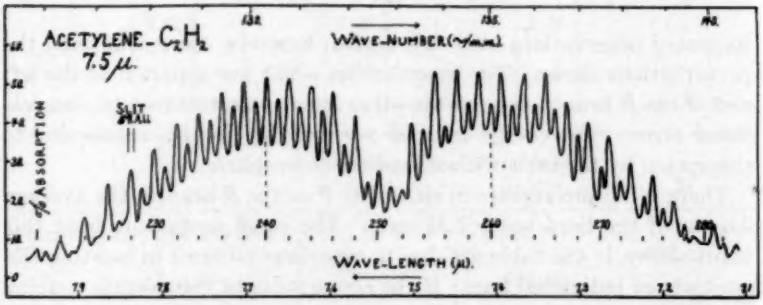

FIG. 3.

markably well with the value given above by the classical formula on the assumption of a linear molecular model.

[9] Eucken, A. ZS. für Electrochemie, *26*, pp. 377–383; 1920.

TABLE 3. *Acetylene—Region of 7.5μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
220	1258.05		236	1293.96		252	1330.83		268	1369.58	
		1.68			2.25			2.40			2.20
1	59.73		7	96.21		3	33.23		9	71.78	
		2.79			2.24			2.45			2.41
2	62.52		8	98.45		4	35.68		270	74.19	
		2.37			2.35			2.38			2.50
3	64.89		9	1300.80		5	38.06		1	76.69	
		2.14			2.34			2.28			2.58
4	67.03		240	03.14		6	40.34		2	79.27	
		2.33			2.28			2.41			2.23
5	69.36		1	05.42		7	42.75		3	81.50	
		2.16			2.30			2.49			2.68
6	71.52		2	07.72		8	45.24		4	84.18	
		2.22			2.18			2.40			2.46
7	73.74		3	09.90		9	47.64		5	86.64	
		2.23			2.30			2.60			2.35
8	75.97		4	12.20		260	50.24		6	88.99	
		2.18			2.26			2.21			2.39
9	78.15		5	14.46		1	52.45		7	91.38	
		2.31			2.27			2.53			2.56
230	80.46		6	16.73		2	54.98		8	93.94	
		2.28			2.25			2.35			2.18
1	82.74		7	18.98		3	57.33		9	96.12	
		2.19			2.37			2.59			
2	84.93		8	21.35		4	59.92		281	1400.91	
		2.22			2.42			2.29			
3	87.15		9	23.77		5	62.21		2	03.00	
		2.24			2.49			2.31			
4	89.39		250	26.26		6	64.52		3	06.00	
		2.28			2.31			2.61			
5	91.67		1	28.57		7	67.13				
		2.29			2.26			2.45			

	Coinciding with line no.	Wave number ν/cm	Δν
Maximum of Envelope, P Branch	240	1303.14	
			23.12
Minimum of Envelope; Band Center		1326.26	
			23.98
Maximum of Envelope, R Branch	260	1350.24	

Region of 7.5μ (Fig. 3, Table 3): In this band the P and R branches again consist of sharply defined absorption lines which are alternately strong and weak. The alternation of intensities is well marked throughout both branches. It may be noted that the even numbered lines from 220 to 250 (the strong lines of the P branch) form a regular sequence with the even numbered lines from 252 to 282 (the weak lines of the R branch). Similarly, the weak lines of the P branch form a regular sequence with the strong lines of the R branch. It is possible that one of the lines near the center of the band represents a faint Q branch.

Computations can be made of the mid-positions between strong lines which are symmetrically placed in the P and R branches. The values thus obtained range progressively from 1327.3 cm^{-1} (from lines 248 and 253) to 1329.5 cm^{-1} (from lines 220 and 281). This shift is sufficient to yield a sure indication of convergence toward lower wave-numbers. The type of convergence found here is extraordinary in infra-red bands.

The average displacement of the maxima of the envelopes of the P and R branches from the approximate center of the band is taken as the $\bar{\nu}_r$ in the classical formula cited above. This value, $\bar{\nu}_r = 23.5$ cm^{-1} leads to a determination of the molecular moment of inertia $I = 2.1 \times 10^{-39}$ gr-cm^2. These results are in close accord with those obtained for the 13.7μ band.

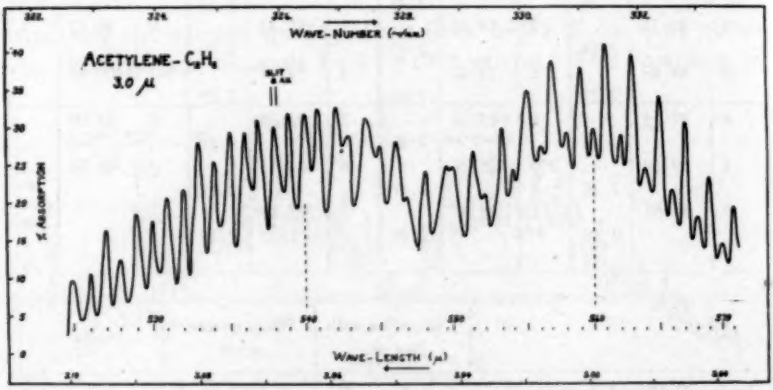

FIG 5.

The spacing of the fine structure near the center of the band has an average value of $\Delta\nu = 2.35$ cm^{-1} (from lines 235–245 and 255–265). This, when substituted in the formula of the quantum theory, again gives the value $I = 2.4 \times 10^{-39}$ gr-cm^2.

Region of 3.0μ (Fig. 5, Table 5): The absorption curve shown in the figure represents the fifth complete run taken over this region. The gas content was readjusted and the slit widths and the reading

TABLE 5. *Acetylene—Region of 3.0μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
525	3226.04		537	3256.15		549	3287.07		561	3314.18	
		2.81			2.70			1.17			2.44
6	28.85		8	58.85		550	88.24		2	16.62	
		2.62			2.26			3.16			1.96
7	31.47		9	61.11		1	91.40		3	18.58	
		2.24			2.54			2.17			2.20
8	33.71		540	63.65		2	93.57		4	20.78	
		2.73			2.30			3.11			2.30
9	36.44		1	65.95		3	96.68		5	23.08	
		2.50			3.01			1.90			2.12
530	38.94		2	68.96		4	98.58		6	25.20	
		2.47			2.07			2.25			2.31
1	41.41		3	71.03		5	3300.83		7	27.51	
		2.52			2.81			2.21			2.05
2	43.93		4	73.84		6	03.04		8	29.56	
		2.55			2.30			1.93			2.06
3	46.48		5	76.14		7	04.97		9	31.62	
		2.44			2.54			2.35			2.23
4	48.92		6	78.68		8	07.32		570	33.85	
		2.62			1.91			2.46			1.89
5	51.54		7	80.59		9	09.78		1	35.74	
		2.43			3.00			2.17			
6	53.97		8	83.59		560	11.95				
		2.18			3.48			2.23			

	Coinciding with line no.	Wave number ν/cm	Δν
Maximum of Envelope, P Branch	540	3263.65	
			24.30
Minimum of Envelope; Band Center		3287.95	
			24.00
Maximum of Envelope, R Branch	560	3311.95	

intervals were decreased after each of the successive runs. The data presented here represent the culmination of these trials which apparently employs the ultimate resolution of which the apparatus is capable.

The band in this region resembles the 7.5μ band in some respects and the 13.7μ band in others. The absence of a pronounced Q branch constitutes a resemblance to the former, while there are resemblances to the latter in the intensity variations in the P branch. The connection between the strong and weak series of lines is obscured by the convergence which exists in this band. The lines are found to converge in the direction of higher wave-numbers. This is shown by the fact that the mid-position, as computed from corresponding pairs of lines, shifts progressively from 3287.7 cm^{-1} (from lines 549 and 550) to 3284.7 cm^{-1} (from lines 528 and 571). This is the type of convergence usually found in vibrational-rotational bands, and is opposite to that of the 7.5μ band.

The value of $\bar{\nu}_r$ computed[10] from the maxima of the envelope is 24.1 cm^{-1}. A value of the moment of inertia $I=2.0\times10^{-39}$ gr-cm^2 is thus obtained, which is quite consistent with previous computations from the classical formula for a linear molecular model.

The average spacing of the lines is $\Delta\nu=2.34$ cm^{-1} (from lines 535–545 and 555–565). This leads to a moment of inertia $I=2.4\times10^{-39}$ gr-cm^2, which is identical with the previous values obtained from the formula of the quantum theory.

Regions of 3.7μ and 2.5μ (Fig. 4, Table 4): For both of these regions of relatively weak absorption, the 8 cm cell was completely filled with gas at atmospheric pressure. The curves obtained are included in the

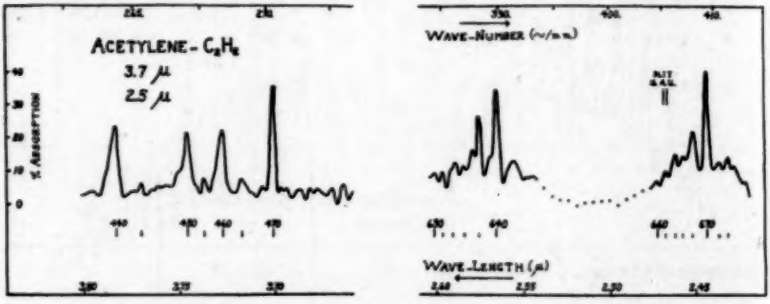

FIG. 4.

one figure. Due to the wide separations between the absorption maxima, it is probable that these may be explained as individual Q branches.

The positions of the four prominent maxima for the 3.7μ region have been calculated and are included in the table. Little weight is attached

[10] The doublet separation is 48.3 cm^{-1}. A value of 41.1 cm^{-1} was given in a recent publication (see footnote 1). The latter value was obtained from an unresolved curve.

to the slight irregularities in the absorption curve occurring between these maxima, as they may be due in part to observational error. The region actually covered in the run at one minute intervals of arc extended to 2830 cm^{-1}, without revealing any important maxima other

TABLE 4. *Acetylene—Regions of 3.7μ, 2.5μ.*

Line no.	Wave no. ν/cm	$\Delta\nu$	Line no.	Wave no. ν/cm	$\Delta\nu$
440	2643.2		638	3882.3	
		26.5			15.6
450	2669.7		640	3897.9	
		13.3			
460	2683.0		668	4077.6	
		19.2			14.4
470	2702.2		670	4092.0	

than those shown. In the other direction, additional observations were taken at five minute intervals to 2500 cm^{-1}; but no further indications of absorption were noted.

The fine structure obtained in the 2.5μ region reveals signs of regularity. Two distinct regions of absorption are noted here in the vicinities of 2.45μ and 2.55μ respectively, a marked resemblance existing between these two bands. Tabulation has been made of the positions of the four most prominent maxima, although several of the weaker ones also undoubtedly represent real lines. The run taken over the central portion of the curve at 2½ minute intervals of arc is indicated in the figure by individual points. No indications of absorption are revealed here over a comparatively wide range.

The supposition advanced by Hettner (loc. cit.), that the 3.7μ and 2.5μ bands are harmonic with the 7.5μ band, is not confirmed by the fine structure obtained for the separate bands. In fact it is hardly conceivable that the apparent differences between the so-called fundamental and harmonics can be reconciled. Final conclusions will not, however, be drawn in this paper.

The structure obtained in these minor regions does not obviously form a part of the same spectrum which has been obtained in the principal regions. The possibility that the minor regions are due to an impurity must, therefore, be considered. But, in view of the work of Coblentz and Burmeister, it is improbable that they are due to impurity.

ETHYLENE

The ethylene was obtained from the Ohio Chemical and Manufacturing Company. The chemical analysis given by the manufacturers shows a purity of more than 99.5 per cent, the impurities listed being nitrogen, oxygen and methane. The amount of the latter impurity present is given as 0.02 per cent.

The four principal regions of absorption, indicated by Coblentz at 10.5, 6.9, 5.3 and 3.3μ respectively, have all been examined. The smaller maximum shown at 2.3μ has also been investigated and fine structure obtained. At 4.9μ there has been found a faint band of which slight indications appear on Coblentz' curve. Small protuberances on the prism curve which were tabulated by Coblentz at 11.8μ and 5.8μ have shown no fine structure, although slight general absorption exists in these regions. The minor absorption maximum at 4.3μ has not been investigated, as the available energy in this region is too low, due to the strong absorption of the carbon dioxide of the atmosphere.

Region of 10.5μ (Fig. 6, Table 6): The intense central maximum at 950 cm^{-1}, of which Coblentz' curve shows evidence, undoubtedly represents a Q branch. The interpretation of the remaining portions of the band as P and R branches is not, however, quite certain. The

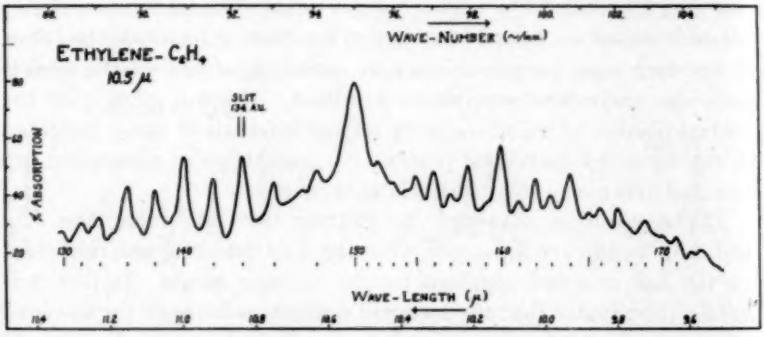

FIG. 6.

entire band has been completely examined several times, and the outstanding characteristics of the curve may safely be taken as real. That is, intensity relations for the lateral maxima which appear in the figure are repeated in various measurements, and the fainter lines lying between the more intense ones are recurrent in the region to the right of the central maximum. Of the faint lines lying near the center of

the band, only those are tabulated whose positions have been confirmed by additional runs.

The spacing of the lines in the *P* branch varies progressively from 6.05 to 7.41 cm^{-1} (from lines numbered 136 to 146). The intense lines in the *R* branch, bearing the even numbers from 156 to 164, show a

TABLE 6. *Ethylene—Region of 10.5μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
134	890.51		148	940.34		158	978.90		164	1006.80	
		6.07						4.91			5.01
6	896.58		150	949.67		9	983.81		5	1011.81	
		6.05						3.82			3.72
8	902.63		2	955.46		160	987.63		6	1015.53	
		6.33						4.89			5.01
140	908.96		5	965.26		1	992.52		7	1020.54	
		6.77			4.85			4.72			
2	915.73		6	970.11		2	997.24		9	1028.30	
		6.94			4.21			4.00			
4	922.67		7	974.32		3	1001.24		171	1037.33	
		7.41			4.58			5.56			
6	930.08										

	Coinciding with line nó.	Wave number ν/cm	Δν
Maximum of Envelope, P Branch	140	908.96	
			40.71
" " " Q "	150	949.67	
			37.96
" " " R "	160	987.63	

more irregular spacing which varies between the limits 8.73 and 9.61 cm^{-1}. The band as a whole shows a doublet spacing of 78.7 cm^{-1} ($2\nu_r$), which is considerably greater than that found in the acetylene bands.

Regions of 6.9, 5.3, and 4.9μ (Fig. 7, Table 7): The absorption bands for these three regions have all been included in a single figure, due to their marked resemblances in structure. Each consists of *P*, *Q*, and R branches, the *Q* branch being in every case sharp and well pronounced. The doublet spacings for the three bands are apparently the same, as

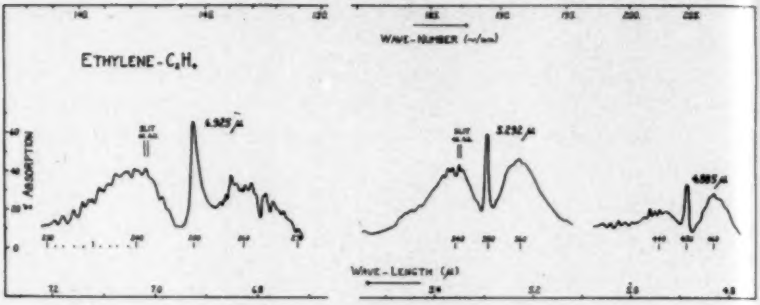

FIG. 7.

TABLE 7. *Ethylene—Regions of 6.9, 5.3, 4.9μ.*

Line no.	Wave number ν/cm	Δν
231	1389.5	
		3.2
232	1392.7	
		4.0
233	1396.7	
		3.5
234	1400.2	

	Coinciding with line no.	Wave number (ν/cm)	Δν
Maximum of Envelope, *P* Branch	240	1420.8	
			23.1
" " " *Q* "	250	1443.9	
			21.0
" " " *R* "	260	1464.9	
Maximum of Envelope, *P* Branch	340	1866.5	
			23.2
" " " *Q* "	350	1889.7	
			23.8
" " " *R* "	360	1913.5	
Maximum of Envelope, *P* Branch	440	2023.2	
			23.8
" " " *Q* "	450	2047.0	
			23.6
" " " *R* "	460	2070.6	

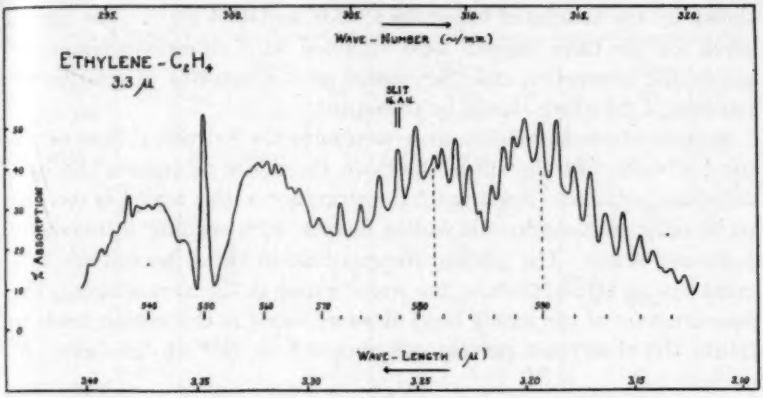

FIG. 8.

TABLE 8. *Ethylene—Region of 3.3μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
570	3036.5		581	3084.9		587	3115.8		593	3154.7	
		8.4			3.5			4.7			6.0
2	44.9		2	88.4		8	20.5		4	60.7	
		7.5			6.0			4.5			8.6
4	52.4		3	94.4		9	25.0		5	69.3	
		8.5			5.6			7.4			8.0
6	60.9		4	3100.0		590	32.4		6	77.3	
		8.6			4.3			7.2			5.9
8	69.5		5	04.3		1	39.6		7	83.2	
		8.3			6.5			7.8			
580	77.8		6	10.8		2	47.4				
		7.1			5.0			7.3			

	Line no.	ν/cm	Δν
Maximum of Envelope, *P* Branch	540	2965.9	
			22.3
" " " *Q* "	550	2988.2	
			24.4
" " " *R* "	560	3012.6	
Maximum of Envelope, *P* Branch	581	3084.9	
			22.5
Minimum of Envelope; Band Center		3107.4	
			25.0
Maximum of Envelope, *R* Branch	590	3132.4	

shown by the tabulated values 44.1, 47.0, and 47.4 cm^{-1}. The curves given for the three regions were obtained with different amounts of gas in the absorption chamber, hence no comparisons of relative intensities of the bands should be attempted.

Several efforts have been made to resolve the individual lines of the band at 6.9μ, but the curve shown in the figure represents the best definition attained. Apparently the structure in this region is too fine to be fully resolved by slit widths of 60A with reading intervals of $\frac{1}{2}$ minute of arc. The marked irregularities in the R branch are to a great extent attributable to the water vapor in the atmosphere. The fine structure of the strong band of water vapor in this region tends to falsify the absorption percentages obtained for the ethylene gas. At

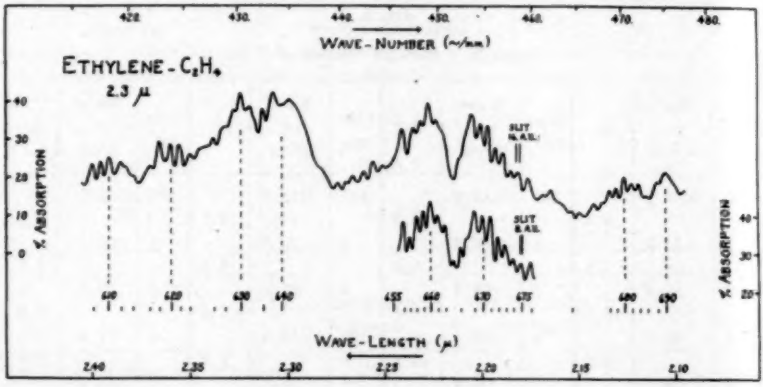

FIG. 9.

the extreme left end of the P branch four lines have been separated, and their positions show an average spacing of approximately 3.6 cm^{-1}.

The band at 5.3μ exhibits an extremely narrow and well defined Q branch. Some indications of fine structure appear in the P branch but further resolution could not be obtained. In the direction of greater wave-lengths, the run was extended out far beyond 5.8μ without revealing any additional regions of absorption. It is true that pronounced irregularities in the curve were noted in the region of 6.0μ, but these are quite evidently due to experimental error introduced by the strong band of water vapor in the atmosphere.

As the absorption at 4.9μ is very low, it was found necessary to increase the gas content of the cell in order to obtain the curve as shown

TABLE 9. *Ethylene—Region of 2.3μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
608	4165.6		656	4460.7		665	4512.4		674	4575.8	
		7.8			6.4			7.8			8.8
609	73.4		7	67.1		6	20.2		5	84.6	
		7.9			6.6			7.1			10.8
610	81.3		8	73.7		7	27.3		6	95.4	
					7.4			7.4			
618	4226.7		9	81.1		8	34.7		8	4684.9	
		9.9			6.8			8.7			8.6
620	36.6		660	87.9		670	43.4		9	93.5	
		8.6			7.9			8.0			8.6
622	45.2		2	95.8		1	51.4		680	4702.1	
		9.8			7.9			8.1			8.7
624	55.0		4	4503.7		2	59.5		2	10.8	
					8.7			8.2			8.0
						3	67.7		4	18.8	
								8.1			

	Coinciding with line no.	Wave number ν/cm	Δν
Maximum of Envelope, *P* Branch	610	4181.3	
			26.6
Minimum of Envelope; Band Center		4207.9	
			28.7
Maximum of Envelope, *R* Branch	620	4236.6	
Maximum of Envelope, *P* Branch	630	4302.2	
			22.1
Minimum of Envelope; Band Center		4324.3	
			16.9
Maximum of Envelope, *R* Branch	640	4341.2	
Maximum of Envelope, *P* Branch	660	4487.9	
			27.6
Minimum of Envelope; Band Center		4515.5	
			27.9
Maximum of Envelope, *R* Branch	670	4543.4	
Maximum of Envelope, *P* Branch	680	4702.1	
			26.9
Minimum of Envelope; Band Center		4729.0	
			21.1
Maximum of Envelope, *R* Branch	690	4750.1	

in the figure. Here we again see evidences of incompletely resolved fine structure in the P branch.

Region of 3.3μ (Fig. 8, Table 8): This is a double band, the first member of which consists of P, Q, and R branches and is centered at 3.35μ. The second band has P and R branches only and lies in the neighborhood of 3.22μ. The fine structure for the latter band has been resolved, the positions of some twenty-three lines being tabulated. In the P branch the spacing is fairly regular between lines 572 and 580, the average $\Delta\nu$ being 8.3 cm^{-1}. Between lines 580 and 589 the structure is more obscure, but it is again clear toward the right end of the R branch. Here the average $\Delta\nu$ is 7.5 cm^{-1} (from lines 589 to 596).

The doublet separation of the band at 3.35μ is taken as 46.7 cm^{-1}. This value is apparently identical with that obtained for the three bands shown in the previous figure. A value of 47.5 cm^{-1} is tabulated for the doublet at 3.22μ.[11] Due to the nature of the envelope, considerable latitude is possible here in the choice of the maxima.

Region of 2.3μ (Fig. 9, Table 9): The simple absorption maximum shown by Coblentz resolves into two intense doublets flanked by a faint doublet on each side. In other words, there apparently are in this region four distinct bands, each consisting of P and R branches only. The doublet separations as recorded in the table are 55.3, 39.0, 55.5, and 48.0 cm^{-1}. For convenience in distinguishing between the four bands, they will be referred to in the following discussion as the 2.4, 2.3, 2.2, and 2.1μ bands respectively.

The complete run, which is represented, was taken at intervals of one minute of arc. The band at 2.2μ was subsequently re-examined at intervals of one-half minute of arc and with a slit width of 8A. With the consequently improved definition the small detached curve shown in the figure was obtained. The absorption scale for this curve is found at the right side of the figure. The best defined lines have a spacing of about eight waves per centimeter. The spacing of the few lines obtained in the 2.1μ and the 2.3μ bands does not differ greatly from this value, nor does that of the 3.22μ band. In the 10.5μ band the spacing in the P branch is somewhat smaller, and between intense lines in the R branch it is somewhat greater. It may be that there is a

[11] This value is larger than the doublet separation of 42.6 cm^{-1} which was previously obtained from the unresolved band (see footnote 1).

common predominant spacing in all of the bands of ethylene which have been resolved into lines. In the bands which have not been resolved, the spacings must be much smaller.

ETHANE

The three principal regions of absorption shown by Coblentz have been investigated, together with the minor region at 2.4μ. The work of Coblentz indicates that the two remaining absorption maxima in the vicinities of 8μ and 10μ are due to impurities in the gas used, and hence these regions were not examined.

The ethane gas was furnished in a cylinder by the Carbide and Carbon Chemicals Corporation. The purity was stated to be 90 per cent, the balance being specified as methane or propane or both.

The features introduced into the curves by the presence of methane as impurity in the gas can be easily detected, as the spectrum of methane is well known. Attention will be called to them in the proper places. The effects caused by propane, if present, are more troublesome to determine as its spectrum is not known. Therefore, some runs were made with propane in the cell by way of control. The propane was also obtained from the Carbide and Carbon Chemicals Corporation who state that the purity is 97 per cent, the balance being ethane and butane. The control runs show that propane has regions of absorption which overlie very closely the 6.8μ, 3.4μ, and 2.4μ regions of ethane. There is little or no absorption due to propane at 12.2μ, where ethane has intense absorption.

The curves obtained for propane not only overlie those for ethane in the three regions above mentioned, but they bear a very striking resemblance to them. The two sets of curves have many features in common, which occur in both sets in the same spectral position and with about the same intensity. However, if any of the features in the curves obtained for ethane were due primarily to the presence of propane as impurity, these features should appear greatly intensified in the curves obtained when the cell was filled with propane. Such intensification was nowhere found. The presumption is, therefore, that the curves for ethane are not markedly affected by the impurity of propane which may be present. It would perhaps have been better to have purified the ethane by fractional distillation. But the above mentioned control runs would have been necessary even then, and it is believed that these runs furnish fairly conclusive evidence in themselves.

Region of 12.2μ (Fig. 10, Table 10): This band shows a single succession of absorption maxima which increase in intensity as the center of the band is approached. Such a series of maxima has been previously found for ammonia and has been interpreted as a series of Q branches.[12]

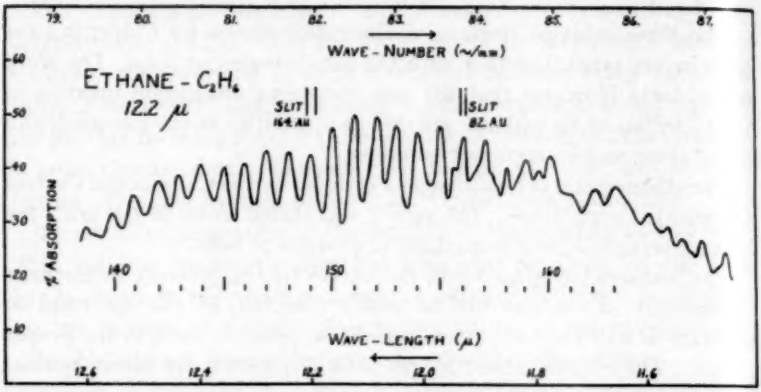

FIG. 10.

TABLE 10. *Ethane—Region of 12.2μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
140	796.46		145	809.15		151	824.67		156	838.21	
		2.43			2.53			2.81			2.75
1	798.89		6	811.68		2	827.48		7	840.96	
		2.78			2.54			2.40			2.73
2	801.67		7	814.22		3	829.88		8	843.69	
		2.42			2.62			2.68			2.43
3	804.09		8	816.84		4	832.56		9	846.12	
		2.51			2.58			2.80			
4	806.60		9	819.42		5	835.36				
		2.55			2.64			2.85			
			150	822.06							
					2.61						

The spacing of the maxima obtained for ethane is regular between 11.8μ and 12.6μ. To both sides of this region the structure becomes more obscure as the absorption decreases. To the right of the line numbered

[12] Colby, W. F. and Barker, E. F. Physical Review, *29*, p. 923; 1926.

150, the increased energy available permitted a decrease in the slit widths, thus improving the definition. This improvement, however, did not offer sufficient resolution to clear up the portion of the curve

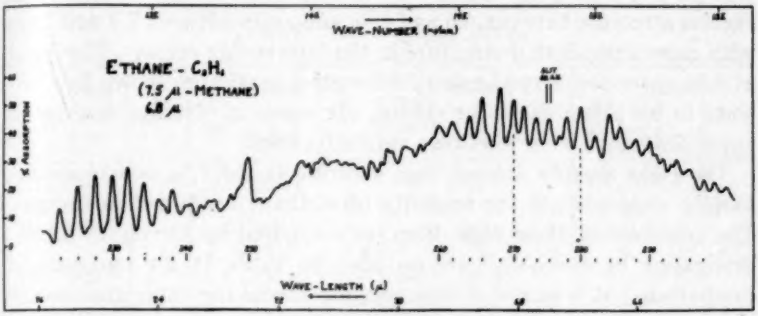

FIG. 11.

TABLE 11. *Ethane—Regions of 7.5, 6.8μ.*

Line no.	Wave no. ν/cm	Δν	Cooley, methane lines	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
224	1322.5		1323.0	260	1442.5		276	1482.3	
		5.1				4.9			4.2
6	27.6		28.3	2	47.4		7	86.5	
		5.1				5.7			2.4
8	32.7		33.3	4	53.1		8	88.9	
		5.1				5.0			5.2
230	37.8		38.3	6	58.1		280	94.1	
		4.6				6.2			5.5
2	42.4		42.9	8	1464.3		2	99.6	
		4.9				4.9			5.5
4	47.3		47.8	270	69.2		4	1505.1	
		4.4				4.1			4.2
6	51.7		52.5	2	73.3		6	09.3	
		4.1				4.3			6.3
8	55.8		56.7	4	77.6		8	15.6	
						4.7			
250	1379.4								

at the right of the figure, which remains incompletely resolved. At the left end, the curve was extended far beyond 13.3μ without revealing anything of further interest.

The fine structure obtained between lines 140 and 159 yields an average $\Delta\nu$ of 2.6 cm^{-1}. The spacing of the lines in this region shows a slight convergence in the direction of lower wave-numbers.

Region of 6.8μ (Fig. 11, Table 11): The absorption curve reveals regular structure between 6.6 and 6.9μ and again between 7.4 and 7.6μ, with more complicated structure in the intervening region. The band at 6.8μ corresponds to the sharp absorption maximum shown by Coblentz in his prism curve for ethane. It yields an average spacing of approximately 4.9 cm^{-1} between successive lines.

The eight sharply defined lines occuring in the 7.5μ region are definitely assignable to the impurity of methane contained in the gas. The positions of these eight lines, as computed by Cooley in his investigation of methane,[13] are included in Table 11 for purposes of comparison. It is seen that each position checks the value obtained in the present work within about 0.5 cm^{-1}.

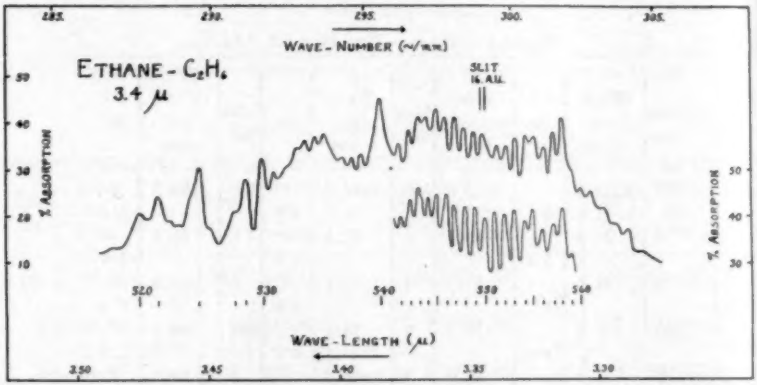

FIG. 12.

Since the absorption of methane is practically negligible between 6.9 and 7.4μ, the complexity of the structure in this region cannot be attributed to the impurity of methane. The presence of propane, on the other hand, would undoubtedly be a complicating factor, but would not account for such prominent features as the No. 250 line in the ethane curve. This absorption maximum apparently belongs to the spectrum of ethane.

Region of 3.4μ (Fig. 12, Table 12): A run was taken over this region at one minute intervals of arc and this was supplemented by a run at

[13] Cooley, J. P. Astrophysical Journal, *62*, pp. 73–83; 1925.

one-half minute intervals over a portion of the curve. This supplementary run shows a regular spacing which averages 3.3 cm^{-1} between lines 541 and 559. A slight convergence again exists in the direction of lower wave-numbers.

TABLE 12. *Ethane—Region of 3.4μ.*

Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν	Line no.	Wave no. ν/cm	Δν
522	2882.5		542	2965.2		548	2983.8		554	3004.4	
					2.9			3.3			2.7
524	2895.5		3	68.1		9	87.1		5	07.1	
					3.0			3.5			3.7
528	2910.9		4	71.1		550	90.6		6	10.8	
					3.1			3.5			3.7
530	16.3		5	74.2		1	94.1		7	14.5	
					3.2			3.4			3.0
540	54.8		6	77.4		2	97.5		8	17.5	
					2.8			3.2			3.1
541	61.9		7	80.2		3	3000.7		9	20.6	
		3.3			3.6			3.7			

The prominent features of the main curve for the 3.4μ region may safely be ascribed to ethane, as the propane band does not exhibit maxima corresponding to lines 524 and 540. The effect of the impurity of methane is slightly noticeable in the region between lines 553 and 558. Here the shape of the envelope for the ethane curve is distorted by the superposed *Q* branch of methane.

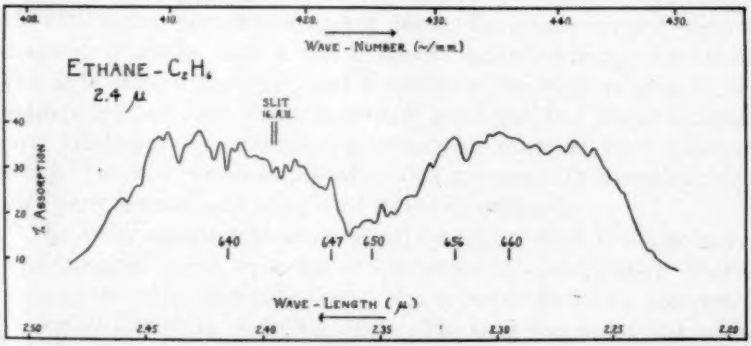

FIG. 13.

Region of 2.4μ (Fig. 13): The curve shows two main regions of absorption, the approximate maxima of which are separated by 220 cm^{-1}. An additional run taken over a portion of the curve at one-half minute intervals and with slits of 8A revealed no evidence of uniform or simple fine structure. The lines numbered 647 and 656 coincide in position with absorption maxima of methane tabulated by Cooley.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF MICHIGAN,
DECEMBER, 1927.

New Methods in Geometrical Optics. By Charles S. Hastings. 103+vi pages. 23 illustrations. The Macmillan Company, New York.

The first two chapters are devoted to a derivation of the first order equations of imagery by a method in which the curvatures of the refracting surface and of the incident and emergent wave fronts are employed in the formation of the equations rather than object and image distances and radii of curvature. The equations as derived are applied to develop the theory of the telescope and microscope and of plane mirrors in considerable detail.

Following this there is a novel and excellent discussion of the chromatic aberrations and different forms of color correction in which the method of treatment is based on the application of differentiation in connection with the development of the first order equations already given in the previous chapter. A relatively brief discussion of the different monochromatic aberrations and a general treatment of different optical systems concludes the work. The volume contains many helpful and constructive criticisms of present types of optical design which are the outgrowth of the author's long affiliation with Dr. J. A. Brashear and his successor, J. B. McDowell. In the appendix there is given a novel discussion of the mirage.

I. C. GARDNER

THE PHOSPHORESCENCE OF CALCIUM TUNGSTATE INDUCED BY X-RAYS

By Frank E. Swindells

ABSTRACT

The rate of decay of a very phosphorescent sample of calcium tungstate was determined photographically and found to fit the empirical equation of Becquerel, $I^{-n}=a+bt$, within the experimental error, from thirty seconds to five minutes after the exposure to x-rays. The phosphorescence of this sample could not be detected photographically more than 50 hours after the exposure of 300 milliampere-seconds at a distance of 30 cm from the target. Under the same conditions the phosphorescence of normal calcium tungstate disappeared in one minute. The intensity of the phosphorescence was found to be closely proportional to the product of the intensity of the x-rays and the time of exposure up to a limiting value, beyond which increased exposure caused a negligible increase in the phosphorescence. In general, these properties are quite similar to those of the "phosphors" of Lenard and others.

This investigation consists of some physical measurements of the phosphorescence of calcium tungstate following its exposure to x-rays. The results may be of some theoretical interest and are of practical importance both to the maker and user of calcium tungstate intensifying screens commonly used in radiography. Very little is known about the cause of the phosphorescence. Samples prepared in different ways and from different lots of raw material show a wide variation in the intensity of the phosphorescence and at the same time may have approximately the same intensity of fluorescence, but practically nothing is known of the elements which may act as activators.

The results given below were obtained with two samples of calcium tungstate. One, designated as "phosphorescent calcium tungstate," shows phosphorescence to a marked degree; the other, "normal calcium tungstate," shows such a small amount under ordinary conditions that it is difficult to detect, and is similar to the product used in the manufacture of intensifying screens of good quality. These samples were fabricated into intensifying screens for convenience in manipulation. The screens were inspected for thin spots and other irregularities, only perfect specimens being used in the experiments.

The x-ray equipment consisted of a radiator type Coolidge tube, with tungsten target, operated at a potential of approximately 60,000 volts peak. The filament current was adjusted by hand, and could be varied from 2 to 10 milliamperes. The tube was supported below a table covered with heavy sheet lead, with several windows 6 by 25

mm, located directly above the target of the tube. These openings were provided with lead shutters.

The first point to be investigated was the rate of decay of the phosphorescence after the x-ray excitation has ceased. The photographic plate was mounted in a specially constructed plate holder, open at the ends and with a removable cover held in place by springs and guides at the sides. The plate, a 4″ by 5″ Eastman D. C. Orthochromatic, was placed on the bottom of the holder with the emulsion side up, and a slightly larger piece of very thin transparent celluloid laid over it so that it overhung the plate by about 1 cm at each end. The ends of the celluloid were then fastened to the wooden base of the holder with thumbtacks. Thus the plate was securely attached to the holder and the sensitive surface protected from scratches. The screen whose phosphorescence was to be studied was cut into a strip the same width as the inside of the holder (13 cm), and 25 cm long. It was laid over the plate with the active side against the celluloid covering and the spring cover attached. In this way the screen was held in contact with the plate and could be drawn across it without opening the holder. One end of the screen was extended about 10 cm beyond the holder and the holder mounted on the lead table so that this portion of the screen was directly above the openings. The tube was adjusted so that the distance from the target to the screen was 30 cm. The shutters were closed and the x-ray machine started, the filament current being regulated to 5 ma. One shutter was opened and after 30 seconds another. When another 30 seconds had elapsed the x-ray machine was shut off. In this way two phosphorescent spots were produced on the screen. After a known time interval the screen was rapidly drawn through the holder until the phosphorescent spots were in contact with the plate at the side nearest to the windows. After an interval of 15 seconds the screen was moved 8 mm and again allowed to remain in contact with the plate for 15 seconds. This operation was repeated until the other side of the plate was reached, a series of stops being provided to properly space the positions of the screen. This procedure resulted in the production of a series of latent images of the spots extending across the plate, which when developed showed decreasing density corresponding to the decrease in intensity of the phosphorescence.

Since it is very difficult to duplicate the development conditions exactly, it was necessary to calibrate each plate in order to make the results obtained with different plates comparable. This was done by

exposing small portions of the plate to light of known intensities, for the same time interval used in recording the phosphorescence. The source of light was a miniature tungsten lamp mounted in a light proof box with a translucent screen at one end. The intensity was varied by means of a series of apertures of known area placed in front of the screen. The plates were developed for five minutes at 18°C in the following developer solution which was prepared immediately before use from purified chemicals dissolved in the order given in 250 ml of distilled water:

Sodium carbonate	5 grams
Potassium bromide	0.125 grams
Sodium sulfite	6.25 grams
Pyrogallic acid	1.25 grams

The plates were then fixed, washed and dried, and the densities measured with a Martens-Maximovitch densitometer.

TABLE 1. *Sample of calculations—Plate no. 1*

A. Determination of gamma:

Stop no.	Log rel. intensity	Density	
1	1.50	0.40	
2	2.10	0.86	$\gamma=0.745$
3	2.45	1.11	

B. Correction of Observed Densities:

t_1	t_2	t_m	30 sec. 5 ma.		60 sec. 5 ma.	
			D_{obs}	D_{cor}	D_{obs}	D_{cor}
30	45	37.5	0.83	0.78	1.02	0.96
45	60	52.5	0.78	0.73	0.97	0.91
60	75	67.5	0.73	0.69	0.92	0.86
75	90	82.5	0.70	0.66	0.88	0.83
90	105	97.5	0.66	0.62	0.86	0.81
105	120	112.5	0.62	0.58	0.83	0.78
120	135	127.5	0.58	0.54	0.78	0.73
135	150	142.5	0.52	0.49	0.73	0.69
150	165	157.5	0.48	0.45	0.68	0.64

are given. The first two columns of the second part of the table show

The results from a typical plate are shown in Table 1. In the first part the densities obtained by exposures to light of known intensities

the time in seconds after the stoppage of the x-ray excitation for the start and finish of each photographic exposure and the third column the average time of each exposure. The observed densities are given in the fourth and sixth columns.

Where a series of exposures at constant time and varying light intensity is made it is well established that for most photographic emulsions a considerable region is found where the photographic density is proportional to the logarithm of the light intensity. If the observed density be plotted against the logarithm of the intensity for different development times, a series of straight lines will be obtained in this exposure region which, if extrapolated, have a common intersection point on or slightly below the log I axis.[1] This relation is expressed by an equation:

$$D=\gamma(\log I-\log A) \tag{1}$$

where D is the photographic density, I the light intensity, γ a constant whose value depends upon the time of development, and A a constant depending upon the speed of the emulsion and the units used to express the intensities. Where the family of development curves intersect on the log I axis, as was found to be the case in these measurements within the limits of experimental error, A is independent of the development time. Therefore to reduce the observed densities to the same value of γ and make the results of different plates comparable, it is only necessary to substitute in the equation:

$$\frac{D_1}{D_2}=\frac{\gamma_1}{\gamma_2} \tag{2}$$

which is readily derived from (1). By plotting the densities obtained from the known intensities against log I, γ was determined. The densities observed with the phosphorescent light were then arbitrarily reduced to $\gamma=0.7$ by equation (2). These are shown in the fifth and seventh columns of Table 1, and in Table 2 the mean values taken from a number of plates are shown.

An approximate calculation of the relative intensities can be made by means of equation (1), and the values so obtained are also given in Table 2 and plotted in Fig. 1. The first intensity in the 60 second

[1] F. Hurter and V. C. Driffield, J. Soc. Chem. Ind., *9*, p. 455; 1890; S. E. Sheppard and C. E. K. Mees, "Investigations on the Theory of the Photographic Process," Longmans; 1907; A. H. Nietz, "Theory of Development", Van Nostrand, 1922; and others.

exposure series is assumed to be 1.00. It should be noted that these intensity values are not of the same order of accuracy as the densities, due to the probable difference in the sensitometric constants of the photographic emulsion for the calibrating light and the phosphorescent light, which probably have different effective wavelengths. In correcting the densities this consideration is of slight importance, due to the small magnitude of the corrections, but in estimating the intensities

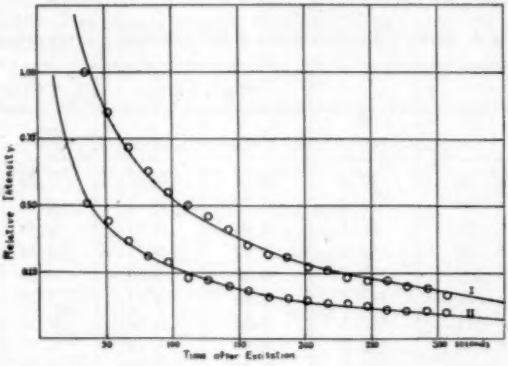

FIG. 1. *Decay of phosphorescence of phosphorescent calcium tungstate. Curve I. 60 seconds, 5 ma.* $I^{-1/3}=0.83+0.0051t$. *Curve II. 30 seconds, 5 ma.* $I^{-1/2}=1.17+0.0073t$.

it may introduce considerable error. Ross[2] has shown that the variation of γ with the wavelength is the least for orthochromatic plates of any emulsion studied, and is not considerable except in the extreme violet. Owing to the lack of spectrophotometric data on the phosphorescent light, which is very faint compared with ordinary light sources, it is impossible to estimate the magnitude of this error.

A number of equations proposed for the $I-t$ relation were applied to the data of Table 2. The empirical equation of Becquerel[3]:

$$I^{-x} = a + bt \tag{3}$$

was found to fit best, but the range of intensities was not great enough for a rigorous test. The solid lines shown in Fig. 1 are calculated from this equation.

[2] F. E. Ross, "The Physics of the Developed Photographic Image," Van Nostrand, pp. 74–5; 1924.

[3] P. Pringsheim, "Fluorescenz und Phosphorescenz im Lichte der Neueren Atomtheorie," 2nd edition, Springer, p. 98; 1923.

The preceding measurements were made on the "phosphorescent calcium tungstate." Similar curves could not be obtained for the "normal calcium tungstate," for the phosphorescence under these conditions is not sufficient to give any blackening of the photographic plate. In order to get some comparison between the two samples, and also an indication of the final duration of the phosphorescence, a different procedure was followed. A number of small pieces of the screen

TABLE 2. *Decay of phosphorescence of phosphorescent calcium tungstate*

t_1	t_2	t_m	30 sec. 5 ma.		60 sec. 5 ma.	
			D_{cor}	I	D_{cor}	I
30	45	37.5	0.78	0.51	0.98	1.00
45	60	52.5	0.73	0.44	0.93	0.85
60	75	67.5	0.68	0.37	0.88	0.72
75	90	82.5	0.62	0.31	0.84	0.63
90	105	97.5	0.60	0.29	0.80	0.55
105	120	112.5	0.54	0.23	0.77	0.50
120	135	127.5	0.52	0.22	0.74	0.46
135	150	142.5	0.48	0.20	0.71	0.41
150	165	157.5	0.46	0.18	0.66	0.35
165	180	172.5	0.43	0.16	0.64	0.32
180	195	187.5	0.42	0.16	0.62	0.31
195	210	202.5	0.41	0.15	0.58	0.27
210	225	217.5	0.38	0.14	0.57	0.26
225	240	232.5	0.38	0.14	0.54	0.23
240	255	247.5	0.36	0.13	0.52	0.22
255	270	262.5	0.32	0.11	0.52	0.22
270	285	277.5	0.30	0.11	0.49	0.20
285	300	292.5	0.31	0.11	0.47	0.19
300	315	307.5	0.28	0.10	0.45	0.17

were simultaneously exposed to the x-rays, and brought in contact with the plate at different times after the x-rays had been shut off. They were allowed to remain in contact with the plate for approximately a month in the case of the "phosphorescent" material and an hour for the "normal" salt, these times having been previously determined as many times the exposures required for the complete cessation of the phosphorescence. The resultant series of blackenings, after deduction of the photographic density of the unexposed portion of the plate may be taken roughly as a measure of the phosphorescent energy remaining in the salt at the time it is brought in contact with the

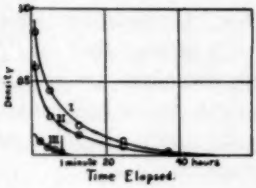

FIG. 2. *Decay of phosphorescence. Curve I. Phosphorescent calcium tungstate 60 seconds, 5 ma. Curve II. Phosphorescent calcium tungstate 30 seconds, 5 ma. Curve III. Normal calcium tungstate 60 seconds, 5 ma.*

TABLE 3. *Relation between excitation and phosphorescence—phosphorescent calcium tungstate*

Photographic exposure 1 hour. $t_m = 4.5$ hours.

Filament current ma	Time sec	Distance cm	Exposure ma sec. per cm²	D_{cor}	Relative intensity I	
2	300	30	0.667	0.64	0.8	
5	120	"	"	0.54	0.6	0.7
10	60	"	"	0.59	0.7	
2	600	"	1.333	0.84	1.6	
5	240	"	"	0.83	1.5	1.5
10	120	"	"	0.82	1.5	
2	900	"	2.000	0.95	2.3	
5	360	"	"	0.94	2.2	2.2
10	180	"	"	0.92	2.1	
2	1200	"	2.667	1.07	3.4	
5	480	"	"	1.05	3.2	3.2
10	240	"	"	1.04	3.1	
2	1500	"	3.333	1.12	4.0	
5	600	"	"	1.12	4.0	4.0
10	300	"	"	1.13	4.1	
2	1800	"	4.00	1.22	5.5	
2	2100	"	4.67	1.25	6.1	
2	2400	"	5.33	1.33	7.9	
2	2700	"	6.00	1.36	8.8	
2	300	12.5	3.84	1.14	4.3	
2	600	"	7.68	1.41	10.3	
2	900	"	11.52	1.54	15.8	
2	1200	"	15.38	1.61	20.0	
2	1500	"	19.20	1.67	24.6	
2	1800	"	23.04	1.69	25.7	
2	2100	"	26.88	1.70	26.9	
2	2400	"	30.72	1.67	24.6	

photographic plate, or the "Lichtsumme" of Lenard.[4] These results are shown in Fig. 2. It will be seen that for "phosphorescent calcium tungstate" approximately two days are required for the intensity to fall below the threshold value for orthochromatic plates, whereas with "normal calcium tungstate" only about a minute is required with the same stimulation value.

TABLE 4. *Relation between excitation and phosphorescence—normal calcium tungstate*

Photographic exposure 5 min. $i_m = 5$min.

Filament current ma	Time sec	Distance cm	Exposure ma sec per cm	D_{cor}	Relative intensity
2	300	12.5	3.8	0.22	2.0
2	600	"	7.7	0.39	3.6
2	900	"	11.5	0.47	4.7
2	1200	"	15.3	0.49	5.0
2	1500	"	19.2	0.49	5.0
2	1800	"	23.0	0.50	5.2
2	2100	"	26.9	0.51	5.4
2	2400	"	30.7	0.49	5.0

The relation between the intensity of phosphorescence and the total energy of the stimulus was investigated by similar methods. The data given in Tables 3 and 4, and Fig. 3, show that the intensity is pro-

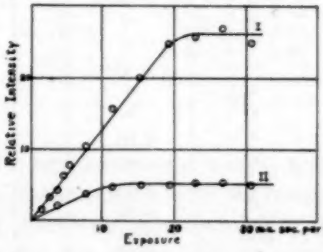

FIG. 3. *Relation between excitation and phosphorescence. Curve I. Phosphorescent calcium tungstate. Curve II. Normal calcium tungstate.*

portional to the product of the intensity and time of exposure of the x-ray excitation until a limiting value is reached, above which increased excitation does not increase the intensity of phosphorescence. In this

[4] P. Lenard and W. Hausser, Heidelb. Ber., 12Abh.; 1912.

behavior calcium tungstate resembles closely the "phosphors" studied by Lenard and others. When the saturation point is reached all of the "centers of phosphorescence" are fully excited and no more energy can be stored. A further resemblance appears in the fact that the application of heat to the phosphorescing salt causes a marked increase in the brilliancy of the phosphorescence, but the duration of the phosphorescence decreases, so that the "Lichtsumme" remains constant. The value of x in equation (3) is said to decrease with increasing temperature, the other constants being independent of the temperature.[5] This is explained by the acceleration of the return of the phosphorescent centers to the normal state by heat, probably by increasing the electronic mobility.

It should be emphasized that for calcium tungstate fluorescence is an entirely distinct process. The two samples showing widely different ability to phosphoresce, had practically the same fluorescence. The fluorescence may be due to the presence of some unknown impurity, probably chemically inseparable and always present in constant proportion, or more probably, associated with some instability in the crystalline structure of pure calcium tungstate.[6]

THE PATTERSON SCREEN COMPANY,
TOWANDA, PA.
OCTOBER, 1927.

[5] H. E. Ives and M. Luckich, Astrophys. J., *36*, p. 330; 1912; Phys. Rev., *34*, p. 156; 1912.
[6] C.f. Tiede and Schleede, ZS. für Electrochemie, p. 304; 1923.

TRANSMISSION AND REFLECTION OF GOLD AND SILVER FILMS

By W. V. Houston* and George Moore

To select the most efficient coatings for the mirrors of interferometers, it is necessary to know the reflecting power and the transmission of thin metallic films as a function of the wavelength and the thickness. This paper describes some rough measurements made on gold and silver films.

The films were deposited on an interferometer plate by cathode sputtering. The measurements were made with a Nutting spectrophotometer made by A. Hilger, and extended between 4600A and 7000A. This range is sufficient to show the regions of superiority of gold and silver. The transmission measurements were made directly on the spectrophotometer. The reflection measurements were made by reflecting the image of the pointolite source into one aperture of the photometer, and allowing the direct light from the lamp to fall on the other. A correction was then made for the different distances through which the light had traveled. To take account of any difference in emission from the lamp, it was reversed and the geometrical mean of the readings was taken as correct. No great precision was attained, but the measurements do show the order of magnitude of the quantities involved, and should be correct within 10%. It is expected, in future work, to extend the range and precision of this work on these and other metals.

The variation with wavelength, for intermediate reflecting powers, was found to be essentially independent of the thickness, and hence can be represented by a single set of values. Table 1 gives the reflection and transmission for various wavelengths in terms of that at 6000A. These values are the averages of those from four plates of different thicknesses. This table shows clearly the maximum of transmission which gives gold its green color by transmitted light.

Table 2 shows the reflecting power and the transmission at 6000A of the plates studied. The sum of the reflection and transmission is considerably less than 100%. The difference is due to the absorption

* National Research Fellow in Physics.

TABLE 1. *Variation with wave length.*

Wave length	Silver		Gold	
	Refl.	Trans.	Refl.	Trans.
7000	1.17	.88	1.29	.80
6800	1.16	.88	1.23	.63
6600	1.09	.87	1.27	.77
6400	1.07	.93	1.14	.87
6200	1.02	.97	1.09	.89
6000	1.00	1.00	1.00	1.00
5800	.97	1.14	.94	1.04
5600	.97	1.21	.83	1.14
5400	.92	1.33	.75	1.25
5200	.86	1.40	.62	1.32
5000	.84	1.46	.55	1.35
4800	.79	1.82	.45	1.16
4600	.72	2.14	.55	.95

in the glass and the metal film, and the reflection from the glass face when the transmission is measured. The variation in the sum, however, represents the variation in the absorption of the metal, since the other

TABLE 2. *Reflection and transmission at 6000A.*

	Silver				Gold			
Refl.	25.8	69.5	80.8	81.0	38.0	49.6	61.7	81.0
Trans.	34.7	2.8	.8	2.0	39.0	27.1	14.7	2.5
Sum	60.5	72.3	81.6	83.0	77.0	76.7	76.4	83.5

quantities are almost constant. The sum for the silver films is somewhat less than that given by Fabry and Buisson[1], but the transmission of the uncoated glass ranged around 80%, and this probably explains the difference.

For use with the Fabry-Perot interferometer we have the equation for the intensity of the maximum[1]

$$I_{max} = t/(1-r)$$

where t is the transmission and r is the reflection. For the resolving power of the simple interferometer we have[2]

$$\lambda/\Delta\lambda = \pi n r^{1/2}/(1-r),$$

[1] Fabry and Buisson, Journal de Physique, *8*, p. 190; 1919.
[2] Houston, Phys. Rev., *29*, p. 478; 1927.

and for the compound interferometer,

$$\lambda/\Delta\lambda = \pi n r^{1/2}(1+R^2)^{1/2}/(1-r)$$

where n is the order of interference and R is the ratio between the interferometers. Thus the intensity depends upon t, while a high resolving power requires a large value of r.

From this point of view the gold film is seen to be superior around 6000A, since for the same reflecting power there is considerably greater transmission. From Table 1 it can be seen that the gold is increasingly superior toward higher wavelengths. Between 5000 and 6000A gold and silver are about equally good, but below 5000A the reflecting power of the gold drops so low that the silver is much superior to it.

These observations confirm the experience of workers with interferometers who use gold films for the red and infrared regions in preference to the silver.

NORMAN BRIDGE LABORATORY,
CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CALIFORNIA,
AUGUST 1, 1927.

An Introduction to Clinical Perimetry. By H. M. Traquair, M. D., F.R.C.S., Ed. Assistant Ophthalmic Surgeon, Royal Infirmary, Edinburgh, Etc. viii+264 pages, with 164 illustrations and a colored plate. C. V. Mosby Company, St. Louis, 1927.

Perimetry consists in the technique of examining the field of vision, together with the science of interpreting the data so obtained. The complexities of the anatomy of the retina and optic pathways are such that injuries at different points produce characteristically different defects in the visual fields. The prime importance of perimetry is, therefore, in relation to the diagnosis of diseases of the eye, and the localization of lesions of the brain, particularly of brain tumors. While the practice of perimetry is more than fifty years old, modern quantitative methods have been used for only the past ten or fifteen years. The present book is a thorough and authoritative treatise on the subject, the most complete that has appeared in English.

The author, after discussing the various methods of examination, incidentally presenting most modestly his own important contributions to this field, reviews in detail the anatomy of the retina, optic nerve and visual pathways, illustrating with numerous figures and charts the characteristic defects produced by lesions at various points. A bibliography of the most important sources is added. The book should be of great value to ophthalmologists and neurologists.

JONAS S. FRIEDENWALD

THE USE OF A MOVING BEAM OF LIGHT TO SCAN A SCENE FOR TELEVISION

By F. Gray

ABSTRACT

The paper is a discussion of a method of scanning employed in a television system. A three dimensional subject is scanned directly by a moving beam of light to produce a picture current in photoelectric cells. This method permits the use of a very intense transient illumination and more than one large aperture photoelectric cell to collect reflected light. These two factors give a highly efficient optical system for producing a picture current at a transmitting station. The image seen at a distant station is the same as if light came out of the photoelectric cells to illuminate the subject and a small aperture lens formed an image of the subject for transmission. The television system transmits only the spacial variations of brightness and not the absolute brightness of the view; consequently, an additional steady illumination of a subject does not affect the reproduced image.

It is the purpose of this paper to discuss certain of the more interesting optical features involved in the system of television recently developed by the Bell Telephone Laboratories.[1] In this system, a three-dimensional view is scanned directly by a moving beam of light and, in order to simplify the electrical amplification and transmission of the photoelectric current produced by the scanning operation, the direct current component of the picture current is suppressed and not transmitted. These two factors give rise to certain rather interesting optical considerations; and aside from a description of the apparatus the paper is chiefly confined to a discussion of the advantages of these two features of operation and their effect on the reproduced image.

Television is the electrical transmission of images of a changing scene so that it can be observed at a distant station. In the practical accomplishment of such a result it is desirable to make the transmission over a limited and preferably over a single telephone line or other equivalent channel of communication.

Such a channel of communication can at most simply transmit an electrical current that varies with time, the channel is incapable of directly transmitting either light or the complicated spacial distribution of brightness that occurs in even the simplest view. The problem of television may therefore be broadly outlined as that of converting a spacial distribution of brightness into an electric current that varies

[1] For a general discussion of the system see "Symposium on Television" Summer Convention, A.I.E.E., Detroit, June 20–24, 1927. See also Bell System Tech. Jour., *6*, October, 1927.

with time, transmitting the varying current to a distant station, and reconverting the current back into light intensity in such a manner as to reconstruct an image of the distant view.

The first step in the television process, that of converting a spacial distribution of brightness into time variations of an electric current, may be accomplished by a scanning process that operates on the view to produce the same effect as if the view were cut up into a series of very fine strips, joined together to form a single long strip, and passed rapidly in front of a light sensitive cell to generate an electric current varying with the brightness along the strip. Since it is desirable to secure equal resolutions both in the direction of scanning and across the direction of scanning, the light sensitive cell should at any one instant collect light from a length of the strip only about equal to its width. In addition, this scanning process should be repeated at least every 1/16 second. This speed enables the persistency of vision to aid in reconstructing the image at a distant station and also permits the observer to follow subjects in motion.

The light sensitive cells that are available for converting light intensity into electrical energy give only very small current outputs even in a reasonably intense illumination. In such a scanning process as that outlined above, the only light available for affecting the sensitive cell must be collected from a small elemental area of the scene; even with an intensely illuminated subject, only a very feeble amount of light can be collected for this purpose. This situation constitutes one of the chief difficulties of television and demands a high efficiency in the optical system utilized to scan the scene. The efficiency that must be secured is determined by three factors: the amount of detail that is to be transmitted, the sensitivity of the light sensitive cell, and the inherent limit to practical amplifying systems. The first factor, the amount of detail that is to be transmitted, decides the elemental area from which light may be collected at any one instant. In the system of television under discussion the scene is scanned in a series of 50 lines; and, at any one instant, light can only be collected from 1/2500 of the view. The second factor is determined, at present, by the sensitivity of the gas-filled photoelectric cell, which is the most sensitive cell capable of following rapid variations in light intensity without a time lag. It is true that, measured in terms of the electric current produced for a given luminous flux, the photoelectric cell does not have the efficiency of certain sluggish types of cells, notably selenium. However, photoelectric cells can now be made with very large apertures;

and, as will be seen further on, the present television system utilizes this advantage in such a manner that the effective sensitivity of the cell may be pushed up to a relatively high value. The third factor, the limitation of amplifier systems, results from the extraneous voltages that are inherently present in conductors and amplifier tubes. The thermal agitations of the electrons in an input resistance to an amplifier generate rapidly fluctuating voltages,[3] and rapid variations in the number of electrons emitted from a hot filament also generate disturbing voltages. For successful amplification the voltage output obtained from a photoelectric cell must be considerably larger than these extraneous voltages. Consequently the cell must receive enough light from the changing elemental area of the view to generate this permissible energy output; a result that can only be secured by a highly efficient optical system and an intense illumination of the subject.

This situation and the advantages of the method used in the present system of television may be best understood by first considering another method of scanning originally proposed many years ago, long before television came within the range of actual accomplishment. In Fig. 1, the subject is intensely illuminated by lights placed in front of it and an image of the subject is formed on the rotating disk by the lens L_1. This disk is pierced by a series of small apertures arranged in the form of a spiral. As the disk rotates these apertures trace across the image one at a time in a series of successive parallel lines each displaced a little from the preceding one so that the entire image is traced over in one revolution of the disk. A frame limits the size of the image so that only one aperture is moving across it at any one time. Light passing through a moving aperture falls on a light sensitive cell and generates a picture current that follows the variations in brightness along strips as they are traced out across the image. In the simplest arrangement a cell with an opening the size of the image on the disk would be placed close to the disk, without the intervention of the lens L_2. In passing, it should be noted that this picture current would reproduce the image as it is formed on the surface of the disk by the lens and that a distant observer would therefore look at a reproduced image having the same characteristics as a photograph of the view taken with the lens at the transmitting station.

In any system, such as that outlined above, which scans an image of the subject as formed by a lens, the efficiency of the system is ultimately

[3] Phys. Rev., *29*, p. 367; 1927.

limited by the aperture of the lens. Moreover, the rapidity of scanning demands a small image and consequently a small focal length lens. The question of efficiency in this case comes back to the familiar limit of the ratio of aperture to focal length in practical lens construction. Experiments show that, with the best $f/1.9$ lens available to form an image that is to be scanned in 50 lines, it would be necessary to illuminate the subject with a 16,000 candle-power arc at a distance of four feet in order to secure enough current output from a photoelectric cell for successful amplification. Television under such conditions would be extremely inconvenient to a subject.

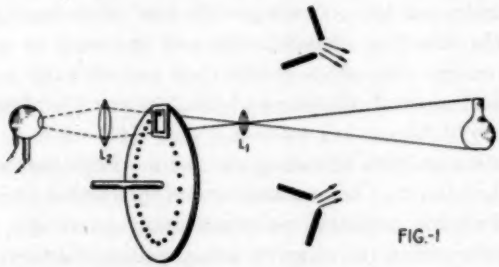

FIG.-1

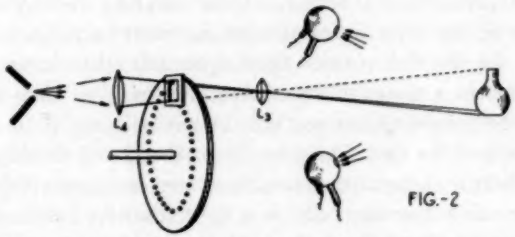

FIG.-2

FIG. 1. *The apertures in the disk scan an image of the subject formed by a lens.*

FIG. 2. *The subject is scanned directly by a moving beam of light projection from apertures in the disk*

These limitations and inconveniences have been evaded in the present system of television by scanning three dimensional subjects directly with a moving beam of light; a method that does not require the formation of an image with a lens. The entire optical system of Fig. 1 is reversed to give the arrangement shown diagrammatically in Fig. 2. The essential features and the arrangements of parts in an actual transmitting station are shown by a photograph (Fig. 3) of an illustrative or skeleton set-up made for this purpose. Light from a 40 ampere Sperry arc is condensed

by a lens to illuminate a small area on the back of a rotating disk. The disk is pierced by a series of 50 small circular apertures about the size of pinholes arranged in the form of a spiral; each aperture is displaced a little toward the center of the disk from the preceding one. A frame with a rectangular opening in front of the d'sk permits light to emerge from only one aperture at a time. As an aperture moves across the opening in this frame, a slender beam of intense light emerges and the lens in front of the disk focuses this beam to throw a moving image of the aperture on the subject seated in front of the apparatus. As a result of this arrangement, a rapidly moving spot of light traces across the subject in a series of successive parallel paths. Each path is displaced a little from the preceding one so that they just barely

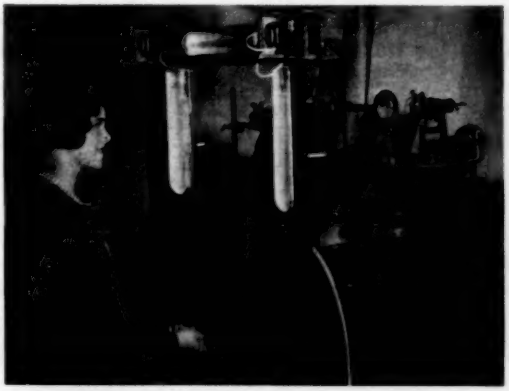

FIG. 3. *An illustrative arrangement of the optical system in a transmitting station.*

overlap; and, in one revolution of the disk, the entire field of view of the apparatus has been completely traced over.

As the spot of light traces across the subject light is diffusely reflected from the subject in all directions, and some of the light that is reflected forward passes into three large photoelectric cells and generates a picture current. The current output from each photoelectric cell is proportional to the intensity of light which it receives, and the cells operate in parallel into a common amplifier system. Consequently, the cells generate a picture current that varies accurately as the brightness of the various elemental areas of the subject traced over by the moving spot of light.

This method of scanning permits two very large gains in the amount of light that can be collected to produce photoelectric currents. The transient nature of the illumination permits a very intense illumination to be used without inconvenience to the subject. In addition, the optical efficiency of the system is not limited by the aperture of a lens but can be increased by using large photoelectric cells and more than one cell connected in parallel.

The cells used in a television transmitting station were specially constructed for the purpose and are probably the largest cells that have ever been constructed. Each cell presents an area of 40 square inches to collect light; and the three cells of a station give an effective aperture of 120 square inches, which is utterly beyond the aperture of any lens that might be used to form an image.

With this large collecting area and the strong light intensity that can be used for the transient illumination, the cells give an electrical

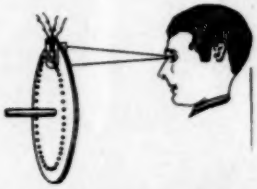

FIG. 4. *Apparatus for reconstructing the image. The neon lamp behind the disk is operated directly from the amplified picture current.*

output, that though still extremely small, is safely above the minimum amount of energy that can be successfully amplified.

At present we may think of this photoelectric current as highly amplified and transmitted over a channel of communication to a distant receiving station, where it reproduces an image of the subject. The simplest method of reconstructing the image is that illustrated in Fig. 4. It may be very briefly described as follows. At the receiving station the picture current is reamplified until it is strong enough to directly operate a neon glow lamp. The brightness of this lamp is directly proportional to the current flowing through it and its speed of operation enables it to follow the rapidly varying picture current. The lamp illuminates a limited area on the back of a rotating disk similar to the one at the distant transmitting station and rotating in exact synchronism with it. This disk is also pierced with a series of small apertures arranged in the form of a spiral. In front of the disk is a frame with a rectangular opening of such dimensions that an observer sitting

in front of the disk sees only one illuminated aperture at a time. The apertures trace across the frame in successive parallel paths that slightly overlap each other to give a uniform field. As a result of this entire system of television, there is at any one instant in the field of view at the receiving station an illuminated aperture in a position corresponding exactly to the instantaneous position of the moving spot of light on the distant subject; moreover, the brightness of this aperture is directly proportional to the brightness of the corresponding illuminated spot on the distant subject. Consequently, an aperture moving across the frame is continually reproducing the corresponding portions of the distant subject. On account of the persistency of vision an observer looking at the disk continues to see each elemental area of the picture for an appreciable time after it has been reproduced; and, since the disk rotates at 18 times per second, the observer sees the whole image reproduced at one time. This speed of transmission also permits the observer to follow distant subjects in motion.

With this brief survey of an entire television system, we may return to the transmitting station and a discussion of the manner in which the method of scanning affects the reproduced image. In the preceding pages it was assumed that the subject is at the exact position at which the small aperture of the transmitting disk is sharply focussed. As a matter of fact, this condition is not necessary. Light passes in an almost parallel beam through a disk aperture and as a result the slender beams of light sweeping across the regions in front of the transmitter just barely overlap each other even at a considerable distance from the transmitter. Consequently, within wide limits, no confusion results in this respect as the subject moves toward or away from the apparatus. The region covered by the sweeping beams may be imagined as a cone of rectangular cross-section extending out from the lens in front of the disk. To be seen at a receiving station a subject must be located inside of this region of scanning.

It is rather evident that this method of scanning with a moving beam of light will give a good reproduction of a flat subject such as a large photograph or painting. It is not so evident, however, that it operates equally well for a three dimensional subject. The fact that it does, and its influence on the quality of the reproduced image may best be understood by noting that this system is exactly reversible into that shown in Fig. 1. This follows from the general law of optics known as the reversibility of light paths. As far as the geometry of the rays involved at any instant is concerned the system in front of the disk

in Fig. 1 is the same as if all of the rays of light in Fig. 2 were reversed in direction. In this reversed system, rays of light would come out of the photoelectric cells as if they were lamps to illuminate the subject; the lens would form an image of the subject on the disk; and light passing through the scanning apertures would enter a photoelectric cell behind the disk and generate a picture current. There is a slight difference in the geometry of the rays in the two cases due to the fact that in Fig. 1 the entire aperture of the lens would be used to collect light, while in the system of Fig. 2 the light passes through the lens in slender beams. The two systems would be exactly equivalent if the areas of the cell in Fig. 1 and the arc crater in Fig. 2 were the same. The use of a point source in Fig. 2 or of a point photoelectric cell in Fig. 1 is equivalent to the use of a small aperture lens in front of the disk, since the lenses L_2 and L_4 in the positions shown form images of the cell or arc in the projection lenses L_1 and L_3. The small effective aperture of the projection lens gives the apparatus a deep focus as already pointed out.

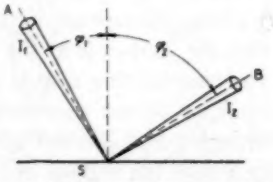

FIG. 5. *Diffuse reflection at a surface.*

Besides this geometrical reversal, it appears that the light intensities involved at any instant are also reversible. This reversibility is rather evident in the case of specular reflection at an elemental area of the subject; because the angle of incidence and the angle of reflections of the light are equal, and the reflecting power of the surface would therefore be the same in either direction. Diffuse reflection at an elemental area of the subject, however, scatters light in all directions; but even in this case the intensities involved are also reversible. This may be realized from the following considerations. In Fig. 5, let I_1 be the luminous intensity (luminous flux per unit solid angle) incident at an angle ϕ_1 over a small area of the surface; and let I_2 be the contribution that this incident light makes to diffuse light leaving the surface at an angle ϕ_2. The illumination of the surface due to I_1 is

$$E = I_1 \cos \phi$$

According to Lambert's Law the reemission from a perfectly diffusely reflecting surface varies as the cosine of the angle from the normal. Consequently the luminous intensity of the light leaving the surface at an angle ϕ_2 is

$$I_2 = KE \cos \phi_2,$$

where K is a constant for the surface; or, by substituting the value of E,

$$I_2 = KI_1 \cos \phi_1 \cos \phi_2$$

Now suppose that this incident light of luminous intensity I_1 is allowed to flow to the surface in the direction ϕ_2, then by an exactly similar process of calculation we find that the contribution made by this light to the luminous intensity I_2 away from the surface in the direction ϕ_1 is

$$I_2 = KI_1 \cos \phi_2 \cos \phi_1$$

which is exactly the same as the expression for the flow in the first direction, a result that necessarily follows from the fact that the equations involve ϕ_1 and ϕ_2 in a perfectly symmetrical manner. In other words, if light incident to an element of surface in a given direction contributes a definite fraction of its value to light leaving the surface in another direction, then light passing to the surface in the second direction will contribute the same fraction of its value to light leaving the surface in the first direction; and the luminous flux is reversible even for perfectly diffuse reflection.

Mat surfaces do not in general obey Lambert's Law. The empirical laws of reflection for such surfaces may however be expressed in a form that involves the angles of incidence and reflection in a symmetrical manner[3]; and it follows that the flow of luminous energy is reversible at reflection from such surfaces.

In the case of semi-mat surfaces, glazed surfaces, etc., that give still more complicated types of reflection, the laws of reflection have not been definitely formulated. Such surfaces appear to give a combined diffuse and compl'cated specular reflection, which, in the absence of data to the contrary, may be taken as an indication that the flow of light energy is probably exactly reversible at reflection from such surfaces. At least, it may be considered as such for all practical purposes of television.

[3] See Walsh's Photometry, p. 114.

The foregoing discussion has shown that at any instant the method of scanning with a beam of light may be considered optically equivalent to the reversed system both in regard to the geometry of the rays and the flow of luminous energy to photoelectric cells. It therefore follows that the photoelectric current produced by this method is equivalent to the current that would be produced in the reversed system. Consequently, the image seen at a distant receiving station has the same characteristics as an image of the subject formed on the surface of the scanning disk by a small aperture lens. It thus follows that, within its range of resolving power, this method of scanning will reproduce three dimensional figures with sharp edges and elevations and depressions just as well as they could be reproduced in a photograph.

The correct position for the observer at the receiving end, Fig. 4, is with his eye at the same position with respect to this disk as that occupied by the lens L_3 at the sending end, Fig. 2. In this position the eye sees the image as it would appear on the sending disk viewed from the lens L_3, that is, the image would be wrong side up but correctly oriented laterally. To correct this inversion the receiving disk, rotating in the same direction as the sending disk, is reversed so that the spiral of apertures winds in the opposite direction; and the two disks are synchronized so that the outer end of the sending spiral and the inner end of the receiving spiral of apertures both enter the field at the same time. The image is thus seen correctly oriented and in correct perspective and size. For other positions of the eye, the image will suffer distortions in perspective exactly similar to those caused by viewing a photograph at a distance different from the focal length of the camera lens. If the receiving disk is larger than the sending disk, or the image magnified, the best viewing distance is increased in proportion.

The lights and shadows of the television image are the same as if light came out of the three large photoelectric cells to illuminate the subject. As a consequence the problem of lighting the subject becomes a problem not of manipulating light sources but of manipulating the photoelectric cells. If the effect of lighting from one side is desired, there should be more photoelectric cells on that side. If the effect of diffused lighting is desired, a large number of cells, or cells of large area, should be disposed all around the subject. Shadows are produced not where no light falls on the subject but at those points from which no light can reach the photoelectric cells.

The size of the reproduced image decreases as a subject moves away from the lens in front of the scanning disk. The brightness of the image

is, however, independent of the distance from this lens and entirely dependent on the distance of the subject from the photoelectric cells. For good reproduction of the human features, which reflect very little blue light to which the cells are sensitive, a person should not be more than a few feet away from the cells.

One question that is frequently asked by those who have not had an opportunity to see the apparatus is what a person sees when he is being scanned. This is readily answered by considering Fig. 2 and imagining a human being as the subject. If he looks toward the apparatus, as he must to be seen face to face by the observer at the distant station, he will see in the lens L_3 an image of the arc crater, as formed by the lens L_4. Although the light forming this image must pass through a pinhole aperture in the disk the image is nevertheless intensely bright; but the subject only sees it when the moving beam passes into his eyes. Since the pupils of the eyes are only an exceedingly small fraction of the total field over which the beam sweeps, the time the subject sees the bright image in the lens is correspondingly small, and is reduced in apparent intensity in the same proportion, this reduction in apparent brightness is such that the subject experiences no discomfort with light of the intensity necessary for scanning purposes.

The character of the reproduced image given by this method of scanning is also affected in certain interesting respects by the fact that, in the present television system, the direct current component of the photoelectric current is suppressed and not transmitted to the receiving station. The theory of this method of transmission may be briefly described as follows.

Considering the view as scanned in one long, continuous strip, we may imagine the variation in brightness along this strip to consist of elevations above and depressions below an average brightness level for the entire strip. The photoelectric current reproduces these elevations and depressions as time variations above and below a corresponding average direct current from the cells. This varying direct current can neither be highly amplified nor transmitted over the usual channel of communication. Such circuits will pass only alternating currents. In the present television system, this situation has been met by amplifying and transmitting only the time shape or time variations of the direct current. The average direct current is suppressed to give a complex alternating current as shown in Fig. 6. This complex alternating current representing the time shape of the photoelectric current

is amplified and transmitted to a distant station. There the current shape is impressed on a local, arbitrarily chosen direct current to give a result such as shown in the lower diagram of Fig. 5. The reconstructed current has the same shape as the original but its average level may not correspond to that of the original picture current. When this resultant current is converted back into light intensity, it reproduces the same variations in brightness as occurred in the original view. However, the average brightness level of the reproduced image may be greater or less than the brightness level of the original view depending entirely

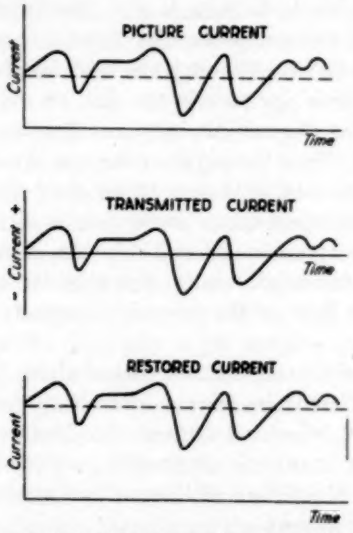

FIG. 6. *The D. C. component of the picture current is suppressed to give a complex alternating current as illustrated by the second curve. After transmission, this complex, alternating current is again impressed on a D. C. current as shown by the last curve.*

on the value of the restored direct current. The restored current is, however, under direct control at the receiving station, and it is varied until the image assumes a normal or pleasing appearance. Experience shows that an exact reproduction of the average brightness level is not as important as it may appear on first consideration; the same setting of the apparatus will serve for a great variety of subject. In other words, vision is more concerned with differences in brightness than it is with absolute values.

The complex alternating current, corresponding to the variations in brightness along the view, may for a still picture be rigorously

considered as a Fourier series or a sum of simple sinusoidal alternating currents of different frequencies. Experience shows that the picture current of the usual moving subject may approximately also be considered as such a series. For a still subject, these alternating currents cover the range of frequencies from that at which the entire view is scanned, say 18 cycles per second, up to about half the frequency at which individual elements of the view are scanned, about 22,000 cycles per second. Motion of the subject does bring in frequencies below 18 cycles; but for practical purposes this may be considered as the approximate lower limit of the frequency range that is required for good reproduction. When the complex alternating current is impressed on a direct current and translated back into a spacial arrangement of brightness along the strips that form the reproduced image, we may think of each alternating current component as operating on a uniform brightness level to remove brightness from the positions corresponding to the troughs of the alternating current and pile this brightness up in the positions corresponding to the crests. The reproduced image is formed by the combined shifting of brightness produced by all of the alternating current components. The higher frequencies reconstruct the fine details of the view; and the lower frequencies produce the more gradual changes in average brightness level from one part of the view to another. Good reproduction demands that all of the current components be transmitted equally well and without a relative shift of the various components with respect to each other, that is, without relative phase shift. A loss of the higher frequencies causes a corresponding loss in resolution of details in the reproduced image. In addition to a loss of detail, the suppression of part of the frequency range may cause multiple outlines of the image. A suppression of the lower frequencies causes an omission of necessary shifts of large regions of brightness to their proper positions in the view, and thus leave abnormal lights and shadows in the reproduced image. For example, suppose that the subject is a field, the upper half of which is white and the lower half black, and that the 18 cycle component of the picture current is suppressed. Then the distortion of the reproduced image may be imagined as that produced by removing brightness from the white half of the field to form a sinusoidal shaped depression of brightness below the correct level, and by piling this removed brightness up in a sinusoidal shaped elevation of brightness level in the black half of the field. A relative shift in the phase of any component with respect to the other components causes a distortion of the image by operating

on the field of uniform brightness level to transfer brightness to incorrect positions in the field. Of course no such distortions occur in a properly operating television system; they are merely mentioned to illustrate the manner in which the image is reconstructed.

This method of transmission when used in conjunction with the present method of scanning leads to an interesting and very convenient feature of the television system, that is, the apparatus scanning the subject may be operated in a lighted room and the additional illumination produces no effect on the reproduced image. Such constant illumination simply increases the average current from the photoelectric cells without affecting the character of the time variations of the current. Since this average direct current is not transmitted it produces no effect on the received image. The room illumination must of course be relatively constant and not vary rapidly with time, otherwise it will affect the reproduction. An illuminating system operating on 60 cycle alternating current will, for instance, produce bands in the field of view at the receiving station.

In the same manner as described above, light from a self luminous body, such as a lamp, in the field of view at the transmitting station simply adds on to the average direct current from the photoelectric cells and is not reproduced at the distant station. A lighted lamp in the field of view will therefore appear as if it were not burning. This, however, is a defect that is of no very great importance.

In conclusion, it may be stated that a complete television system, utilizing the methods discussed in this paper to scan a subject in 50 lines, will reproduce the human features so that a distant person can be seen and easily recognized; and his motions can be plainly followed as he talks into a transmitter and holds a telephone conversation with the observer.

Attention should again be called to the fact that this paper discusses only one phase of an entire television system; no attempt has been made to deal with the equally important features of synchronization, picture current transmission, or methods of enlarging the reproduced image.

BELL TELEPHONE LABORATORIES, INC.,
NEW YORK, N. Y. DEC. 5, 1927.

INSTRUMENT SECTION

A CONVENIENT CHAMBER FOR THE STUDY OF IONS AND ELECTRONS IN GASES

By Leonard B. Loeb and A. M. Cravath

In the course of some years of research on the mobilities and saturation currents of ions and electrons in gases, a convenient form of chamber has been evolved which possibly merits description. A chamber of this type must meet the following requirements.

1. It must have conducting walls. 2. It must be absolutely gas tight. 3. It must be easily demountable for cleaning (especially where reactive gases are used). 4. It must be insulated for electrometric technique with weak currents. 5. The electrodes must be adjustable so that the distances can be changed from outside without opening the chamber. 6. The electrodes must be capable of accurately parallel adjustment and must be sufficiently far from the walls so as to insure uniform fields. 7. The chamber should avoid soldered joints as far as possible, especially such as can open up with the distortion of the chamber due to changing pressures. 8. Contact between sealing waxes and the interior except through long leakage paths between ground surfaces should be avoided. 9. The plates must be visible from outside for cathetometric determination of electrode distances. 10. The chamber should be capable of adaptation to use with photoelectric ionization by ultraviolet light when needed.

These requirements have been recently fairly well fulfilled by a chamber now being used in this laboratory. For the successful execution of it the authors are much indebted to the able mechanical intuition and skill of Mr. Otto Kaehler, one of the mechanicians in the Physics Department.

The essential new element in the construction lies in the attachment of the gauze and plate elements by means of a leveling plate to the cover which carries the collecting plate, enabling the whole of the measuring system to be lifted out of the chamber as an assembled unit for cleaning and readjustment. With this arrangement the outer box or casing becomes very much simplified.

Two cross sections, one parallel and the other perpendicular to the vertical axis, are given in Figs. 1 and 2. The construction is as follows. *A* is a cylindrical chamber of a high quality cast bronze. Its bottom

is 1 cm thick and the walls are 4–5 mm thick with a heavy flange 1.5–1.8 mm thick at the top and bottom. Its outer diameter is 24 cm, and the inner diameter is 20 cm with a depth of 10 cm inside and a height of 13 cm outside. Three small feet β may be cast on the base. At two ends of a diameter are two circular bosses *B B*, 7 cm in diameter and 3 cm from the bottom (see cross section perpendicular to axis). These furnish

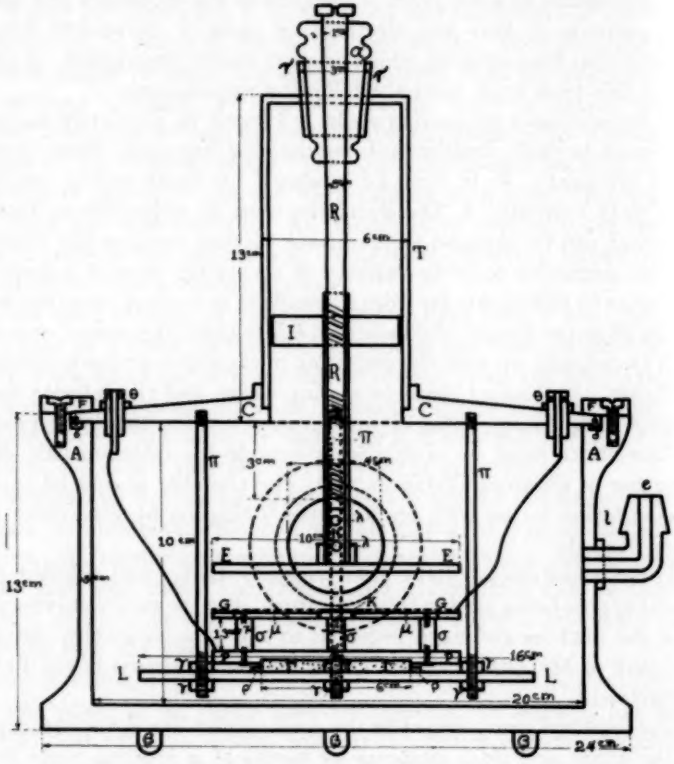

FIG. 1. *Vertical cross section.*

the supports for the circular windows *W*, one of which is of polished fused quartz and the other of which is of glass. These are seated on a shoulder in the boss and may be ground to it. They are secured by either sealing wax or chicle cement applied on the outside. There is another small boss *l* on a diameter at right angles to the axis of the windows for inserting the exhaust vent, *e*, which ends in a ground

tapered male joint for attaching glass tubing. The chamber is machined out on a lathe on the inside so as to get rid of most crevices. It may thereafter be gold plated for use with reactive gases. In gold plating the chamber, the writers' experience has been that some gas, possibly a trace of cyanide, is evolved that exerts a serious influence on the mobilities of positive ions. This can be removed by washing the plated chamber out first with concentrated HNO_3, then after rinsing with water washing with concentrated HCl and finally with dilute NH_4OH in distilled water.

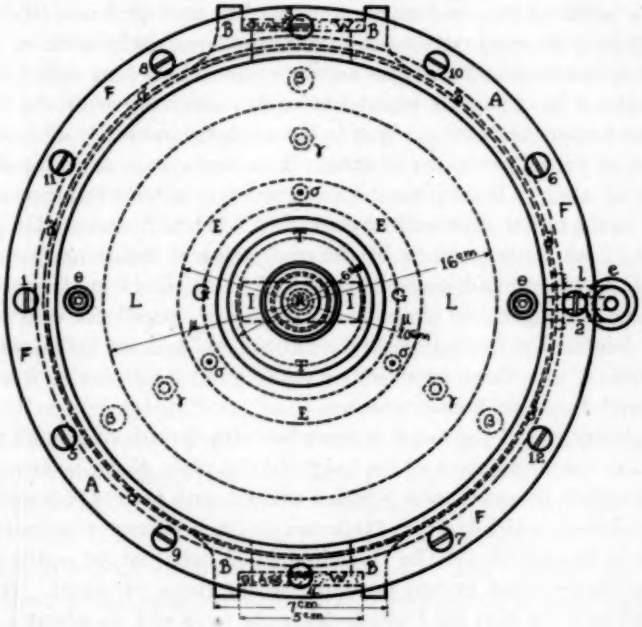

FIG. 2. *Horizontal cross section.*

The inner portion of the flange at the top, of 22 cm diameter, is machined down to a depth of 6 mm, and a rectangular groove δ is cut into it, into which a lead ring gasket is eventually pressed.

The cover *C* of the chamber which carries the measuring unit consists of a bronze casting, 22 cm in diameter, that just fits into the recessed cut in the top. It is 4 mm thick at the thinnest portion and may be somewhat thicker, up to 1 cm, at the center where the supporting tube *T* for the plate is fastened in. It may be made more rigid by a group

of six outside ridges radiating from the center on the outside. The inside surface is machined flat except for the circular flange ϕ of rounded cross section which engages with the center of the lead gasket in the groove δ. Two amber insulators containing the electrical leads from the outside are ground into conical holes cut in the small bosses θ in this casting. They are sealed in with sealing wax or chicle cement from the outside. Into the top C are screwed three brass posts π threaded at their lower end, of 4 mm diameter, and some 9 cm long. At the top on the outside a cylindrical brass tube T, 6 cm in diameter and 12 cm long, is soldered in as indicated. It should be at least 2 mm thick and should be quite rigid. Its top is closed with a carefully soldered brass cap 3–4 mm thick which bears a tube τ some 3 cm long and 3 cm in diameter. τ has a slightly tapered hole, into which is ground the heavy pressed amber insulator α. This is 7–8 cm long and has a diameter of 2.4 cm at the entrance to the tube. It carries a hole, tapering downwards, of about 1.0 cm diameter into which is ground the supporting rod R of the upper electrometer plate E. The amber is secured in place and the joint made gas tight by the application of shellac on the upper half of the two ground joints, on assembling. It can be made more gas tight by running chicle cement or sealing wax around the outer ends of the joints. The insulating surfaces of the amber α are machined and polished. Under these conditions a really good insulation is achieved even with the most humid weather.

The lower end of the rod R is threaded with threads of a small pitch so that a fine adjustment of the height of the plate E can be obtained. An accurately threaded tube N which engages with the rod R is soldered to the plate E, which is 3 mm thick and 10 cm in diameter by means of a hole in its shoulder. The threading in N need not be continuous. It may be threaded in two portions two or three cm apart. It has fastened to it the iron lug I which clears the walls of T by about $\frac{1}{2}$ mm. By the use of an outside electromagnet the plate E can be raised or lowered from outside at will. It is advisable to have in the lower end of H two "breathing" holes λ in order to accelerate evacuation. By means of three holes in a plate L sixteen cm in diameter, the plate can be fastened at any position near the ends of π and adjusted in level parallel to E by means of the nuts γ.

There is on L either a slight recess or a ring ρ into which a circular plane parallel plate glass disk sits snugly. This in turn fits into a recess in a heavy brass plate P, 4–5 mm thick and 10 cm in diameter. The latter is electrically connected to one of the binding posts θ. It carries

screwed to it 3 amber supports σ. These have fastened by means of screws an iron ring μ about 2 mm thick and of 10 cm outer and 9 cm inner diameter, to which is soldered the perforated sheet brass or copper gauze G. This is electrically connected to the outer binding post θ. The under side of the gauze at its center has a small inverted cup K, containing a disk of 1.3 cm diameter coated with Polonium. (If the apparatus is to be used for photoelectrons P and G can be replaced by a single plate P of speculum metal or brass.)

The plate E and the plate-gauze system PG should be *heavily* gold plated in the same bath to prevent contact potentials. They should never be cleaned by anything other than a water paste of $NaHCO_3$ on a stiff brush and rinsed with distilled water. The gauze is fastened tightly over the iron ring and is held flat by tinning both the surfaces to be soldered first and then heating the gauze and ring between heavy weights with the gauze taut until the solder melts and letting them cool together. Differential contraction on cooling then gives a flat rigid gauze. The plate E and the gauze G are adjusted parallel to each other by lowering E until it nearly touches G and adjusting L by means of the nuts γ until a bright light can no longer pass between G and E when viewed from all directions. E can then be raised to a desirable distance 1–1.5 cm and the lock nuts γ tightened. The part C is then placed in the box A and the plate C gently rotated to insure good seating on the gasket (care having been taken to have the gasket δ free from dust, etc.). The heavy cast bronze ring F is then placed over C and the machine screws, 1, 2, 3, 4, etc., are inserted into the holes and tightened. These should be tightened to about the same degree in the order 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, taking up on 1, 2, 3, and 4 again as needed after the first adjustment. The chamber may then be evacuated and after ten minutes the screws should be again tightened as before. No leakage should result under these conditions. If it does a small amount of a vaporless grease may be smeared on the *outside* of the flange ϕ.

Possibly a word might be said about the gauze. The writer used perforated sheet brass of a commercial type used in driers. It is possibly .35 of a mm thick and the number of perforations and their size can be chosen from the large numbers of commercial sizes available. The disadvantage of these gauzes is that in order to get enough ions through, the holes must be so large that some leakage of the fields takes place, which introduces errors into the mobilities. If a wire cloth or screen

of sufficiently fine wires with fine meshes could be procured, such as mentioned recently by H. Mayer,[1] this would be preferable.

The above described chamber has been used by one of the writers[2] now for three months with as troublesome a gas as H_2S, and he finds that it is unquestionably the most successful chamber he has encountered.

PHYSICAL LABORATORY,
UNIVERSITY OF CALIFORNIA,
BERKELEY CALIFORNIA,
DEC. 5, 1927.

[1] Mayer, H. Physik. ZS., *28*, p. 637; 1927.
[2] Loeb and DuSault. Proc. Nat. Acad. Sci., *14*, 1928.

Lens Computing by Trigonometrical Trace. By Colonel J. William Gifford, F.R.A.S., F.O.S., with a foreword by Professor F. Cheshire. Pp. xii+81, with 18 illustrations. (London: Macmillan & Co., Ltd., 1927).

The author of this little volume has long been known in England as an expert optical engineer, who, as Professor Cheshire says in a foreword, "did sterling work in this capacity during the war, giving his services generously." Concerning the book itself Professor Cheshire goes on to say that "the student can thus accept the work set out as that of a thoroughly practical man, which has been tested at every stage."

In the preface the author himself tells us that the book is intended to be "a short and concise handbook on trigonometrical trace as applied to Optics, in as simple a form as possible to meet the needs of the student and beginner." It is based on Steinheil and Voit's famous *Handbuch der angewandten Optik*, published in Leipzig nearly forty years ago, which itself was based on the theories and methods of Ludwig Philipp v. Seidel (1821–1896), professor of mathematics in the University of Munich. Thanks to Dr. J. W. French, an excellent translation of this German work is now available for English and American readers. The notation and processes of trigonometrical computation employed by Colonel Gifford are in the main those adopted by Steinheil and Voit in their practical applications of v. Seidel's theories. The German authors had originally intended to bring out a second volume, which however was never prepared and concerning which Colonel Gifford says in the preface to his book that "a few of the applications, which perhaps would have appeared in their second volume have been set out, in particular several eyepieces of a new type, and a new kind of erector for the terrestrial eyepiece, which has already done good service." In the same place he mentions also various other new contributions that are contained in his work.

The first part of the book comprising twenty-five pages, including the introduction and Chapters I–VI, is a kind of *résumé* of the elements of geometrical optics, which seems rather out of place inasmuch as the reader might certainly be presumed to be already familiar with most of these fundamental principles. The titles of the succeeding chapters are as follows: Trigonometrical trace (Chap. VII, pp. 26–34), The one radius doublet (Chap. VIII, pp. 35–38), Uncemented doublet (Chap. IX, pp. 39–48), Eyepieces (Chap. X, 49–66), Trigonometrical trace of doublet in fullest detail (Appendix I, pp. 67–70), Trigonometrical trace of an apochromatic triple telescope (Appendix II, pp. 71–76), Trigonometrical trace in special cases (Appendix III, pp. 77–79).

A treatise on optical designing and computation by an acknowledged authority, such as the writer of this volume undoubtedly is, would certainly be hailed with joy by other laborers in this vineyard who know only too well that a really satisfactory book on this subject is not only hard to find but indeed has not yet been written. The eager reader who opens the book before us with any such high expectations is doomed to disapointment: whatever its merits may be, it is no *vade mecum* for the student of optical engineering and he need not expect to find here much help in his difficulties. The book does not even pretend to describe the design of optical systems; and while there may perhaps be casual allusions to such subjects as astigmatism, sine condition, coma, distortion, etc., that is all. On the other hand, some of the chapters are of considerable interest, as, for example Chapter VIII on "The One Radius Doublet." Here too, as is the case throughout, the student must be already familiar in some measure at least with the system of computation of Steinheil and Voit; otherwise, he will find it hard to follow the numerical examples which Colonel Gifford uses by way of illustration. Undoubtedly, however, a reader who is informed on the subject will pick up here and there hints and suggestions that will be of use to him in his own work in this field.

J. P. C. S.

A METHOD OF VARYING IN INFINITESIMAL STEPS THE ELECTROMOTIVE FORCE OF A CIRCUIT WHILE AUTOMATICALLY KEEPING THE RESISTANCE OF THE CIRCUIT CONSTANT WHEN THE SOURCE OF THE ELECTROMOTIVE FORCE IS A BATTERY

By Frank C. Walz and Lloyd R. Jackson

In the course of an investigation which is still in progress it was found necessary to keep the resistance of a circuit constant while a battery electromotive force applied to the circuit was varied in infinitesimal steps. The investigation referred to made use of what is generally known as "Dowling's Zero Shunt,"[1] which makes it possible to use a high sensitivity galvanometer to measure very small changes in the total current in a circuit, even though the total current greatly exceeds the range of the galvanometer used. The "Zero Shunt" method consists of shunting a galvanometer with a battery in series with a high resistance, the electromotive force of the battery being adjusted to draw all the normal current through the "Zero Shunt." Any change in the total current will then divide through the galvanometer and the "Zero Shunt" according to the law of parallel circuits. In order not to harm the galvanometer it is necessary to keep the "Zero Shunt" circuit closed and adjust the electromotive force in the "Zero Shunt" circuit in infinitesimal steps by means of the ordinary potentiometer pick-off method. But this in turn varies the "Zero Shunt" resistance which must be kept constant in order that its multiplying power remain the same. Other occasions in which resistance changes caused by varying battery electromotive forces must be compensated arise in investigations employing highly sensitive and critically adjusted oscillating circuits. In such circuits the constancy of frequency, the degree of sensitivity, stability, etc., quite often depend upon the constancy of the circuit resistance. The method presently to be described may also be modified so as to compensate the changes in resistance occurring when the shunt resistance of a galvanometer is varied in infinitesimal steps.

[1] J. J. Dowling, Phil. Mag., *46*, 1923.

Consider the circuit in Fig. 1. Let R represent the total resistance of rheostat bd, R_b the internal resistance of the battery af of electromotive force E, and R_1 the load resistance.

The object of this paper is to determine how R_c, the total variable resistance within the dotted lines in Fig. 1, must vary as a function of the position of the slider c of rheostat bd to secure compensation, and then to consider a combination of rheostats which will automatically give the value of R_c desired for every position of the slider c. It will appear later that R_c will become two rheostats R_c' and R_c'' as indicated within the dotted lines of Fig. 1.

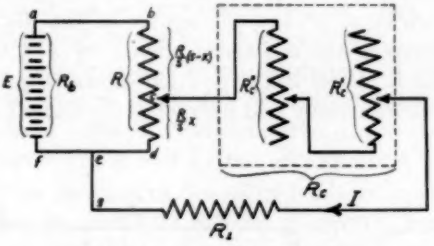

FIG. 1. *Schematic wiring diagram.*

Let s represent the effective length of rheostat bd and x the distance from d to any position of the slider c. Then the resistance of cd is Rx/s and that of bc is $(R/s)(s-x)$, where R/s is the resistance per unit length of the rheostat bd.

Applying Kirchhoff's laws to the various meshes of the circuit the expression for the current I through the load resistance is found to be

$$I=\frac{\frac{x}{s}\cdot\frac{R}{R+R_b}E}{R_1+R_c+\frac{R}{s}x-\frac{(R/s)^2}{R+R_b}\cdot x^2} \tag{1}$$

The denominator represents the total resistance offered the current I and the numerator therefore represents the "effective" electromotive force, and varies from zero to a maximum with x. As the total resistance offered current I is a function of x, it is not constant unless the resistance R_c is made to vary with x in a certain manner. This condition is satisfied and the resistance is constant if R_c is made to vary with x in accordance with the following equation:

$$R_c=\frac{R}{s}(s-x)+\frac{(R/s)^2}{R+R_b}\cdot x^2 \tag{2}$$

For by substituting the right side of eq. (2) for the second term of the denominator of eq. (1), the total resistance becomes (R_1+R), which is seen to be constant and independent of x and therefore of the position of slider c. Compensation has therefore been obtained provided R_c can be made to vary as has been assumed in eq. (2).

Let us next consider the proper design and combination of rheostats which must constitute R_c if it is to vary in the required manner. From eq. (2) it is seen that it will be convenient to obtain the resistance R_c by means of two rheostats, one to give the resistance represented by each term.

In order to obtain the resistance represented by the second term of eq. (2), which varies as x^2, i.e., the square of the distance that the slider moves, consider the resistance offered by a wire-wound cone, Fig. 2. The cone is placed in the position shown to permit its sliding contact to move horizontally and parallel to the slider c of rheostat bd.

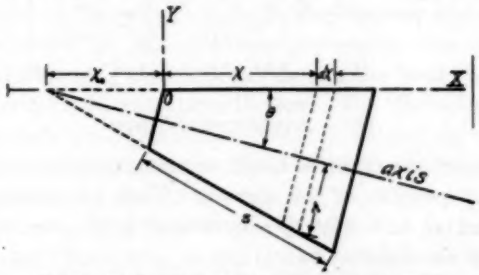

FIG. 2. *Axial-section of a wire-wound cone rheostat.*

An arbitrary length x_0 is left off the vertex end of the cone as it is impractical to make contact or wind wire on a sharp end. Let k represent the resistance per unit length of the wire, and n the number of turns of wire per unit length measured along the generatrix of the cone. The effective length of the cone measured along the generatrix is assumed equal to s the length of rheostat bd. The resistance offered by the cone rheostat between two contact points distance dx apart and at a distance x from the end 0, see Fig. 2, is

$$dR=2\pi rnk\,dx=2\pi(x+x_0)\sin\theta\,kn\,dx \qquad (3)$$

in which $(x+x_0)\sin\theta$ has been substituted for r. By integrating eq. (3) the total resistance offered by the rheostat from the origin to any point distant x is found to be

$$(\pi kn\sin\theta)\,x^2+(2\pi knx_0\sin\theta)\,x \qquad (4)$$

The second "unwanted" term of expression (4), which is linear in x, would not appear if it were not necessary to leave off part of the vertex end of the cone, i.e., if x_0 could be set equal to zero.

That part of the resistance of the cone represented by the first term of expression (4) can be made equal to the second term of equation (2) by equating coefficients of x^2. This gives an equation from which the value of the angle θ of the cone and the coefficient of the second term of equation (4) can be determined after all the other factors are known. But in adopting this procedure, the extraneous resistance represented by the linear term in expression 4 is introduced in the circuit and must be neutralized, i.e., compensated for, for every value of x by some other arrangement as will be discussed below.

In designing a linear rheostat to represent the first term of equation (2), the resistance per unit length R/s of this rheostat can be increased by the already fixed value of $2\pi knx_0 \sin\theta$ to insure the cancelling of the excess resistance introduced by the cone rheostat.

Summarizing, we see that as the slider c moves any distance x the resistance changes are such that in order to compensate, the resistance represented by equation (2) must be introduced in series with R_1. The cone rheostat, represented by R_c' in Fig. 1, with the slider an equal distance x from its end introduces resistance equivalent to the second term of equation (2), and in addition an extra amount. The linear rheostat, represented by R_c'' in Fig. 1, in turn cuts out resistance as represented by the negative part of the first term of equation (2) and at the same time cuts out enough extra to cancel the extraneous resistance introduced by the cone rheostat.

It is obvious, since the sliders of all rheostats considered move equal distances to accomplish compensation, that all sliders can be mechanically controlled as a unit. Referring to Fig. 1 the rheostats within the cotted lines are the two rheostats considered and it will be noted that their sliders move in unison with the slider of rheostat *bd*.

If the value of R_b used in the design of the compensating rheostats is chosen larger than any likely value of internal battery resistance, and the total resistance of the battery branch is always made equal to the chosen value of R_b by introducing resistance in the battery branch, it is seen that the arrangement will permit batteries having various values of resistances and electromotive forces to be used.

It is hardly necessary to point out that the insertion of more batteries in the circuit between e and g, Fig. 1, will not destroy compensation

by this method provided the resistance of the batteries introduced is taken into account. This fact considerably increases the range and usefulness of the arrangement.

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Reports of Progress Committees Optical Society of America. Owing to an oversight in preparing the program for the Twelfth Annual Meeting (Schenectady, October, 1927) no provision was made for the presentation of the reports of the Progress Committees. (Two reports were received although not called for in the program.)

Inquiry as to how to proceed now has been received from one chairman whose committee did not report; and it is presumed that others desire the the same information.

It is understood that the term of Progress Committees expires with that of the President who appointed them; their reports are due during his administration and should normally be made at the last annual meeting in his term of office. However, it is highly desirable that the reports which would normally have been presented at Schenectady should still be made. It is therefore ruled that the presentation of these reports, by Committees of the term, 1926–27, will be in order at either the New York meeting February 24–25, 1928, or the Washington meeting October, 1928; and it is hoped they will be presented at one or the other of these meetings.

Reports of new Progress Committees to be appointed by the present administration will be due at the Fourteenth Annual Meeting, October, 1929, and not in 1928.

IRWIN G. PRIEST,
PRESIDENT

JANUARY 11, 1928.

CONVENIENT FORMS OF MAGNETOMETERS

By S. R. Williams and W. J. Eckert

The magnetometer has shown itself to be a very useful tool for studying the variation in intensity of magnetization as the magnetizing force is increased or decreased. The astatic and vibration free instruments designed by Bozorth,[1] by Tyndall[2] and by Kohlrausch and Holborn[3] have proved to be very satisfactory where minutia of details were desired. They were delicately constructed to give small differential effects, especially at low field strengths. For a general survey of large intervals in magnetization a more rugged and less sensitive instrument can be used. A limit to the sensitivity may be set by adjusting the magnetic moment of the needle and the torque of the fiber to a relation such that the ordinary variations of the earth's magnetic field do not appreciably affect the zero point.

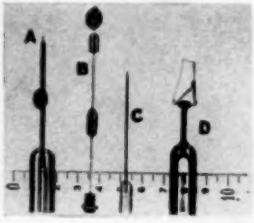

Fig. 1. *Various forms of bell-shaped magnets.*

In trying to improve old forms of magnetometers to be used as wide range instruments the following two designs have been evolved which may prove useful to others. Both forms use the split, bell-shaped magnet such as was formerly used in the moving magnet type of galvanometer. Fig. 1, *A*, *B*, *C*, and *D*, show several sizes of magnets which have been used. Fig. 2 shows the magnetic field surrounding a bell-shaped magnet. Fig. 1, *B*, indicates the way in which an astatic system may be built. The lower magnet has an adjustable ring for more completely astaticizing the group. Two such bell-shaped magnets

[1] Bozorth, J.O.S.A. & R.S.I., *10*, p. 591; 1925.
[2] Tyndall, J.O.S.A. & R.S.I., *9*, p. 465; 1924.
[3] Kohlrausch and Holborn, Ann. d. Phys., *10*, p. 287; 1903.

could be used very satisfactorily for developing an astatic magnetometer, in which one of them would carry the movable ring. The bell-shaped magnets used in these instruments were made from tungsten and chromium steel.[4] Tungsten was by far the better of the two.

The two magnetometers to be described are similar in every respect except in the arrangement of the light source, mirror and scale. In both instruments the magnets are suspended in heavy brass cups filled with oil. The oscillations of the magnets are damped both by the oil

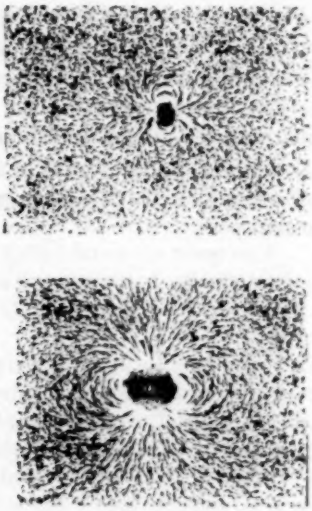

FIG. 2. *Magnetic fields surrounding bell-shaped magnets.* The upper illustration represents magnet *C* and the lower, magnet *A* of FIG. 1.

and the eddy currents set up in the brass cups. Oil which the General Electric Company uses in their oscillographs is excellent for damping purposes. If this is not available, high grade transformer oil may be used.

Fig. 3 is a photograph of the usual type of instrument and Fig. 4 is a vertical cross-section of the same instrument. *B* is a wooden base with leveling screws. *A* is the heavy brass cup for the oil in which the magnet swings. The removable cap, *C*, contains a small window, the glass of which is set at a small angle with the vertical so as to reflect

[4] Margaret Moir, Phil. Mag., *28*, p. 738; 1914.

no light back to the scale. Into the top of this cap is sealed a glass tube of any desired length. The upper end of the glass tube is closed with a torsion head that may be plain, or furnished with a divided circle. The magnet, *M*, with the mirror firmly attached to its stem is suspended by a fairly coarse phosphor-bronze fiber, *P*.

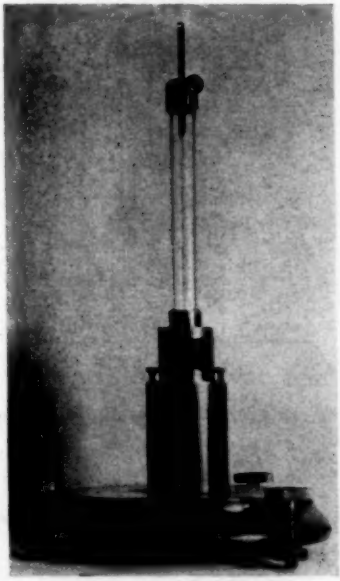

FIG. 3. *A convenient form of magnetometer.*

In this form of magnetometer the needle swings through half the angle passed over by the reflected beam of light. This makes the deflection of the needle less than 45 degrees which can be read with telescope and scale or with scale and lamp. If we wish to follow larger deflections, the light source and mirror must be rearranged.

This has been done in the instrument shown by the photograph in Fig. 5 and by the vertical section in Fig. 6. The light is thrown vertically downward onto the mirror, which is set at an angle of 45 degrees with the horizontal, and thence to the scale *S*. The angle through which the magnet and the beam of light both swing are now the same and 90 degree angles of deflection may be read with ease. The scale should be bent into a circle with the mirror at the center.

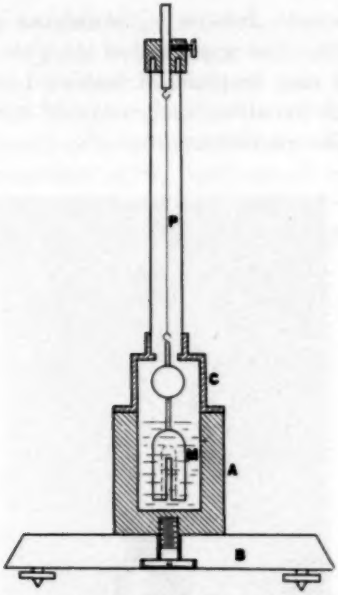

FIG. 4. *A rugged and useful magnetometer.*

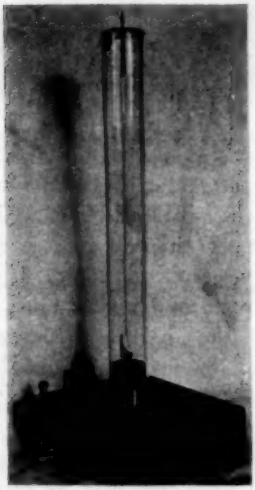

FIG. 5. *A magnetometer for large deflections.*

As may be seen in Fig. 5, the brass cup is placed at the bottom of a glass cylinder with uniform thickness of walls. The top of the cylinder is closed with a piece of good glass which is pierced for carrying the

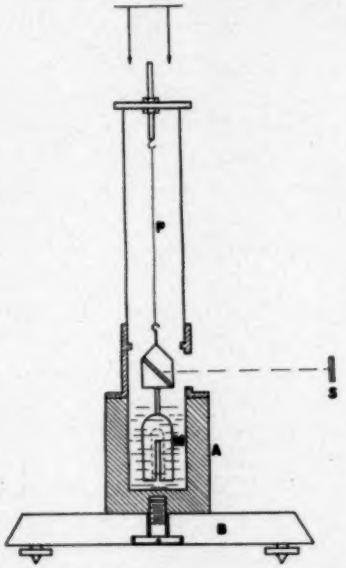

FIG. 6. *Magnet and beam of light are deflected through the same angle.*

stem to which the phosphor-bronze fiber is attached. Fig. 2, *D*, shows the suspension and setting of the mirror used in this form.

Both designs of magnetometers have proved to be very useful instruments in magnetic work.

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A SIMPLE SPECTROCOMPARATOR

By F. Stanley

One of the greatest difficulties met with in spectrum analysis is the determination to the required degree of accuracy of the wave length of any given spectrum line. This is more particularly the case when the more persistent lines or *raies ultimes* of an element are being located. If an alloy is taken and it is required to detect the presence of silver, one of the more persistent lines of the metal is situated at wave length 3280.8A but a persistent line of zinc is close to it at wave length 3282.4A. The silver line given is one of the last to vanish as the quantity of silver is diminished and therefore may be the only line of the metal which can be relied on to determine its presence. Again magnesium has a persistent line at wave length 2852.2A which can be easily mistaken for the sodium line at wave length 2852.9A.

These examples demonstrate the need for making wavelength determinations to an accuracy of one Ångstrom unit or less. To reach an accuracy approaching this by means of a wave length scale is practically impossible unless very high dispersion is used, as however carefully the scale is constructed a slight inequality in the surface of the photographic plate is sufficient to displace the scale, not taking into consideration possible shake in the scale mounting.

Of course a spectrograph giving very high dispersion is an alternative, but if the optical elements are constructed from quartz, the cost is prohibitive and on account of the loss of light in such instruments very little advantage is gained. If wave lengths can be determined with sufficient accuracy there is no doubt that a spectrograph giving a length of spectrum between wave lengths 2200A and 4000A of about seven inches is quite satisfactory for general spectrum analysis, even with such complex spectra as iron or nickel.

Instead of the wave length scale an enlarged chart of the iron spectrum on which the wave lengths are marked can be used and compared with an iron arc spectrum photographed as a comparison above the unknown spectrum, but owing to the difference in size of the two iron spectra the identification of even the iron lines is a most tedious process. To obviate this, an instrument was designed with a suitable prism system so that the chart and the iron comparison spectrum could be seen in

the same field of view, but this necessitated the independent mounting of the chart at some distance from the instrument and this arrangement is not convenient in practice.

A modification of this method has now been adopted which has proved quite satisfactory. A photographic enlargement on paper of the iron spectrum is made of such a size that individual iron lines can be figured in wave lengths and also the position of the more persistent lines of the elements indicated. This enlargement is then reduced to a size approaching the original, but somewhat larger, so that the figures in the negative are still distinct when magnified.

When photographing an unknown spectrum an iron arc comparison spectrum is also photographed above and in contact with the unknown.

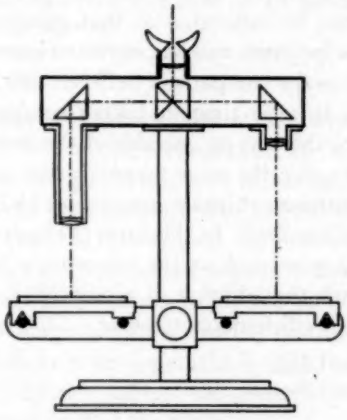

FIG. 1. *Spectrocomparator.*

The comparison spectrum must be obtained by a moving plate with suitable apertures sliding over the spectrograph slit and not by raising or lowering the dark-slide.

The comparator[1] is shown in the accompanying diagram of Fig. 1. This consists of a vertical pillar which carries the optical system and lenses. The base plate is made from substantial brass rods which support a carriage which can be moved along the base so as to bring any part of the spectrum into view. The spectrum plates are mounted on the sliding carriage. On one side the plate of the standard iron spectrum figured in wave lengths; on the other the spectrum with the iron com-

[1] Spectrometric catalogue, Bellingham and Stanley, Ltd., London.

parison. The optical system is arranged to give such a magnification to both fields of the instrument that both the standard iron spectrum on one side and the iron comparison or the unknown spectrum on the other, appear of the same size. The magnification on both sides of the instrument is also arranged that the figures on the standard iron spectrum can be read without difficulty. In the eyepiece of the comparator can be mounted a micrometer scale, or if greater accuracy is required, a micrometer eyepiece with moving cross wires.

If there is now a line in the unknown spectrum the wave length of which is required it is only necessary to bring the iron spectra in both fields into exact coincidence and then by means of the micrometer scale in the comparator eyepiece, the distance between the unknown spectrum line and the nearest figured iron line can be determined. The micrometer scale can be calibrated so that measurements made with it in any part of the spectrum can be converted into wave lengths.

If it is desired to make comparison between two plates taken on the same spectrograph to save time in taking comparison spectra, it is necessary to remove the lens on one side of the instrument and mount in its place a lens to give the same magnification as that on the other. This converts the instrument into a comparator giving equal magnification on both sides of the field. In this form the instrument is also useful for many other purposes such as the comparison of pigments, paper, powders etc., or with the addition of a polarising attachment it may be converted into an efficient photometer.

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A NEW REGISTERING PHOTODENSITOMETER*

By Elmer A. Harrington†

ABSTRACT

A direct-reading, self-recording densitometer with single thermocouple and low-resistance D'Arsonval galvanometer has been constructed and used to measure the relative opacities of the photographic images of the lines in ordinary spectra and in X-ray powder photographs. By suitable gearing to an electric motor the photographic negative is given a slow motion at right angles to a beam of light passing through a horizontal lens system; and at the same time a drum carrying photographic paper, on which a spot of light from the galvanometer is focused, is caused by the same motor to rotate at such a rate that a certain distance on the drum corresponds to a certain distance on the negative. A permanent record of the true distribution of opacities is thus obtained, since the deflections of the galvanometer are inversely proportional to the opacities on the negative.

Preliminary experiments show that the apparatus is dead beat and quick in response; and that it is sensitive, stable, and accurate.

In the spectroscopy of ordinary light and of x-rays an instrument is often needed which will record photographically the varying opacities of the photographic images of the lines in the spectrum. This result can be obtained if the photographic plate containing the series of lines to be measured is caused to move slowly in front of a slit through which a beam of light from a constant source is passed, and the resulting variations in the radiant energy transmitted are recorded by means of a receiver and a galvanometer on a moving photographic paper. The principle involved in such an apparatus is that the amount of radiant energy transmitted by any part of the plate is inversely proportional to the opacity of that part of the plate.

The photometric registration of a spectral plate not only shows more about the nature of the lines than can be seen by viewing the plate directly, but it also produces a continuous record of the opacity variations which is preserved on the photographic paper. The advantage of purely physical methods in such a study is at once apparent since they eliminate the physiological difficulties encountered when the eye is the sole interpreter of the opacities of the lines. A number of instruments, not self-registering, have been constructed and used for comparing the opacities of spectral lines or for measuring the variations

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across a single line, or for such subjective work as the determination of the magnitude of stars.

The first instrument of this kind was the Hartmann microphotometer[1] in which each minute area of the photographic plate was compared with a "photographic wedge," *i.e.*, a plate of continuously changing density. A position of the wedge was found such that the contrast between the image of the wedge and that of the small area of the plate disappeared. Since the observer had to compare areas of some extension it was obviously impossible to detect in this way delicate details as spectral lines.

The extended investigations of Koch[2] resulted in the so-called "self-registering" microphotometer, an apparatus working automatically and provided with a slit. In this instrument Koch rejected the principle of photometry by contrast, and determined the transmission by direct measurement of the transmitted light with the aid of a photoelectric cell. The relative merits of the more important physical densitometers are summarized by Harrison.[3] In a comparison of the various types of receivers Harrison concludes that the thermoelectric type is most satisfactory for direct-reading work and that the photoelectric type, on account of its greater sensitivity and quicker response, is best adapted to the null method.

In the null method the light passing through the plate to be measured is balanced against that through a standard wedge. The null method therefore does not lend itself readily to automatic registration, since it requires two operations—balancing the light and reading the wedge—where one suffices in the direct-reading method. The photoelectric cell gives the highest accuracy in the null method, and with certain additional features can be used for accurate direct-reading work.[4] On the other hand, the lack of linear response of the photoelectric current to intensity of irradiation[5] makes it doubtful if the photoelectric cell can be relied upon in general in a "ratio-of-deflections" method. All available data seemed to indicate the thermocouple as the instrument which best combined simplicity and sensitiveness with convenience and ease of manipulation, and it was therefore selected for this work.

[1] J. Hartmann, ZS. Instr., *19*, p. 97; 1899.
[2] P. P. Koch, Ann. d. Phys., *39*, p. 705; 1912.
[3] G. R. Harrison, J.O.S.A. & R.S.I., *10*, p. 157; 1925.
[4] P. Lambert and I. Chalonge, *Rev. d'Opt. theor. et. instr.*, *5*, p. 404; 1926.
[5] K. S. Gibson, J.O.S.A. & R.S.I., *7*, p. 693; 1923.

DIRECT-READING METHOD

The thermoelectric photometer is a purely physical means for the measurement of relative transmission in negatives. In this instrument, which is based on the "direct-reading" method, a fine pencil of light passes through a slit across which the photographic plate to be examined is moved by a motor. The light transmitted by the plate then falls on a thermocouple which responds to the changes in transmission of the plate as it passes across the beam of light. The variations in the radiant energy received by the thermocouple cause a varying potential across the terminals of a sensitive D'Arsonval galvanometer, and give rise to corresponding variations in the deflections of the galvanometer. A narrow beam of light, reflected from the galvanometer mirror, moves back and forth across the photographic paper on a revolving drum and traces out a curve, the lowest point of which corresponds to the maximum opacity of the series of spectral lines which are being investigated.

In this way a permanent record is produced which represents the transmission gradient, since the deflections of the galvanometer are inversely proportional to the opacities on the plate. The relative rates of movement of the negative and of the revolving drum carrying the photographic paper are arranged to give a convenient scale for the transmission. The height and width of a peak in this curve show the blackness and the width respectively of the corresponding spectrum line in the negative. The area under the curve is a measure of the blackening produced by the light from the line in question, and when the characteristics of the photographic plate are considered it obviously gives more accurate values for the relative amounts of radiant energy emitted by the spectrum lines than can be obtained by visual estimations.

This method gives a quantitative measure of the relative strengths of lines having very different appearance, as in the sharp and the diffuse lines often occurring in the same spectrum. It may also be used for examining the so-called "dashed-pattern" sometimes found in an x-ray powder photograph, when the maximum opacity of the line cannot be taken as the measure of its intensity. The method also eliminates the judgment and the skill required to make accurate photometer settings and consequently it involves no personal errors.

APPARATUS

A general view of the apparatus (except the galvanometer) is given in Fig. 1, and the arrangement is shown diagrammatically in Fig. 2.

The plate to be investigated is supported on a carriage which can be moved along guiding rails attached to the main stage of the instrument. The carriage is given a slow uniform motion by means of a micrometer screw connected through reduction gears to a small motor. Both the screw and its nut were constructed with the greatest care. The pitch

FIG. 1. *Photograph of photodensitometer.*

of the screw is 1 mm and its length is about 37 cm. The plate-holder consists of two parts. The plate is clamped to a frame which may be moved up or down along two vertical rods, screwed into the top of the carriage. The frame is clamped to these rods by means of thumb-screws when the plate has been placed in proper position in front of the

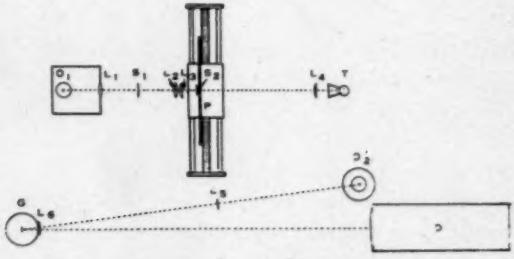


FIG. 2. *Diagrammatic arrangement of apparatus.*

slit. The registering drum D is placed with its axis horizontal in a galvanized iron box which is light-tight except for a narrow horizontal slit in one end. The drum is about 110 cm in circumference and 11 cm wide. The photographic (bromide) paper is held in position on its periphery by two clamps. The shaft on which the drum is mounted

passes through both sides of the box and turns in bearings about four centimeters from each side. One end of the shaft carries a sprocket wheel which is connected by a chain belt and reduction gears to the micrometer screw. The drum therefore turns through a definite angle when the plate advances a millimeter. By changing the size of the sprocket wheel (*i.e.*, number of teeth) on the shaft of the drum, the ratio between the speeds of the plate and the photographic paper attached to the periphery of the drum can be altered as desired. In much of the present work a photographic paper 100 cm long gave the transmission curves for a range of 27.4 cm on the plate under examination, and required 30 minutes at maximum speed of the plate to pass across the slit.

There are two optical systems in the apparatus; the first transmits the radiant energy from the source through the moving plate to the thermocouple, and the second is used to record the resulting deflections of the galvanometer. In the first optical system the source of radiant energy is a straight helical-filament lamp mounted with its axis vertical. The filament O_1 is focused by means of a double convex lens L_1, upon a slit S_1, of slightly smaller dimensions than the filament and parallel to it. The slit, which acts as a virtual source is in turn focused by a double convex lens L_2 and a cylindrical plano-convex lens L_3 upon a second slit S_2, 1 cm long and of variable width (0.12 mm in these experiments). The moving plate P is placed immediately in front of this slit, and the spectral lines are parallel to it. The jaws of the slit were made slightly convex, so that they can touch the emulsion without scratching it when the plate moves. As a result the true slit width and the equivalent slit width do not differ by more than twenty per cent. The beam of radiant energy is finally brought to a focus by a plano-convex lens L_4 upon the thermocouple T.

The constants of the optical system are as follows: L_1 is double convex (f = 6.67 cm), L_2 is double convex (f = 6.67 cm) L_3 is cylindrical plano-convex (f = 6.67 cm), L_4 is plano-convex (f = 5.00 cm). $O_1L_1 = 11$ cm, $L_1S_1 = 11$ cm, $S_1L_2 = 11$ cm, $L_2S_2 = 4$ cm, $S_2L_4 = 35$ cm, $L_4T = 8$ cm.

The light-source used must combine intensity with smallness of dimension, since at best only a small part of the light from the source is transmitted through the slit. These requirements are met in a lamp known technically as "Mazda C, S-24 1/2 clear, street lighting, 6.6 amperes, 1000 lumens, 9.9 volts, straight helical filament, Mogul base." The filament in this lamp is about 1.2 cm long and 1 mm wide. Such a

source when projected gives uniformity of illumination over the slit. The lamp has a large bulb, which decreases its rate of blackening.

The light intensity and conditions of illumination must be maintained constant throughout the experiment (about 30 minutes), because the galvanometer deflections are caused not only by variation in the transparency of the plate but also by any change in the intensity of the source. It is therefore necessary to use storage batteries of sufficient capacity to avoid any progressive decline or gradual fluctuation in the voltage with consumption of current. Any error introduced by a change of voltage is easily detected by connecting a sensitive voltmeter across the terminals of the lamp.

The second optical system has for its source of light the same type of lamp as the first system. It is mounted with its axis vertical, and a narrow slit is placed in front of the filament. The image of the slit reflected from the galvanometer mirror is brought to a focus on the registering drum D by two lenses, L_5 and L_6. L_6 is a plano-convex lens ($f = 133.3$ cm) cemented to the galvanometer window; L_5 is a double convex lens ($f = 50.00$ cm) which can be moved back and forth along the beam until a sharp image is produced on the drum. The dimensions in this system are $O_2L_5 = 31$ cms, $L_5L_6 = 57$ cms, $L_6D = 147$ cms.

A bismuth-silver thermocouple T of small heat-capacity, and hence of short period, was constructed by W. W. Coblentz.[6] Its heat capacity is so small that its reaction does not lag appreciably behind the variations of the incident light. A single thermocouple is used for ease of construction and to minimize fragility. It is mounted in a heavy brass cylinder which is practically air-tight, and it is protected by a glass window of 5 mm diameter. The resistance of the thermocouple and leads is 1.75 ohms.

The chief disturbance experienced in working with a thermocouple in air is due to the unequal heating and cooling of the two junctions by the minute and continual adiabatic variations of pressure of the atmosphere. By putting the thermocouple in an air-tight casing an increased steadiness of the galvanometer is obtained. The "drift" in the thermocouple must obviously be negligible compared to the total deflection in order that the direct-reading method may be used.

A D'Arsonval galvanometer is well adapted to this type of work because of the convenience of manipulation and freedom from outside disturbances as well as high sensitivity. Very satisfactory results have

[6] W. W. Coblentz, Bull. Bureau of Standards, *229*, 1914.

been obtained in the present investigation with a Leeds and Northrup type *R* galvanometer having a resistance of 10 ohms, a critical damping resistance of 22 ohms, a sensitivity of 1 mm per microvolt, and a period of 3 seconds. If the galvanometer is used with an external resistance which is much less than the critical damping resistance—as when the thermocouple is used directly on the galvanometer—it is overdamped and consequently sluggish in its action; if, on the other hand, the galvanometer is used with an external resistance which is much greater than the critical damping resistance it will oscillate about its point of rest. Neither of these conditions gives satisfactory performance. Moreover, since the intensity of the light source is such that with the most dense negatives suitable deflections may be obtained, it is necessary in using thin negatives to reduce the sensitivity of the galvanometer to avoid obtaining deflections beyond the limits set by the width of the drum. This must be done in such a way as to keep the damping approximately critical. However, the sensitivity may be reduced by any desired factor and the damping kept critical by the use of both series and parallel resistance,[7] whose values are chosen to satisfy the equation $1/(R_S+R_T)+1/R_P=1/R_C$, where R_S is the series resistance, R_P the parallel resistance, R_T the thermocouple resistance, and R_C the critical resistance. The deflections of the galvanometer are always proportional to the electromotive force developed in the thermocouple, regardless of the sensitivity of the galvanometer.

The galvanometer and the thermocouple are very sensitive and yet so indifferent to external disturbances that, while in use, they do not need any supervision. Their action is sufficiently rapid and the motion of the mechanism so slow that the record obtained represents the true variation of opacities on the plate. The thermocouple galvanometer system is electrostatically shielded, and all electrical connections are covered with cotton to prevent thermoelectromotive forces at those points.

The registering apparatus need not be placed in the dark, if care is taken that no direct light can fall on the photographic paper on the drum.

The motor which drives the mechanism is 1/20 H.P., direct current, shunt wound, 115 volts, 0.87 amperes, 1750 rpm. The speed of the motor can be reduced to 600 rpm by inserting a slide-wire rheostat of sufficient resistance in series with the motor. When the lines on the

[7] F. Wenner, J.O.S.A. & R.S.I., *11*, p 5; 1925.

plate are very narrow a reduction in the speed of the micrometer screw is necessary to allow the thermocouple and galvanometer to follow the sudden variations in the intensity of radiant energy.

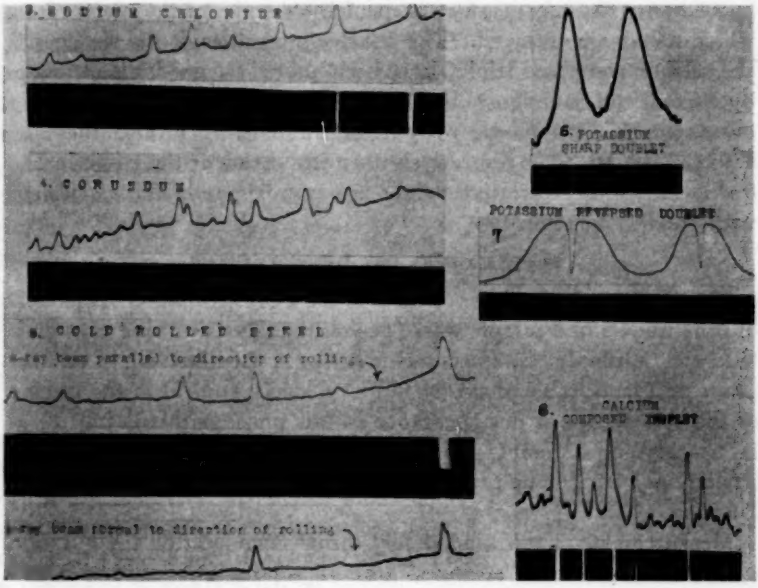
It will be seen that the general scheme of arrangement of the apparatus is not new. However, by refinements in the optical system and by use of a motor-driven mechanism to move the plate and turn the drum a gain in sensitivity and in convenience has resulted. The instrument can therefore by used not only as a photomicrometer but also as a microphotometer. That is, by using a rather wide slit the relative opacities of comparatively wide lines on various parts of the same plate may be studied, or by using a much narrower slit it is possible to measure with high precision the opacity of a restricted area of a line and the variation of this opacity from point to point.

OBSERVATIONS

The observations to be described were necessarily preliminary in character and very limited in scope. While the primary object for which this instrument was constructed was to compare the opacities of the lines in x-ray powder photographs, it was designed for use in any branch of spectroscopy where quantitative measurements of line-intensity and line-structure are desirable. Values of the intensities of spectrum lines are often given with tables of wavelengths or x-ray interplanar spacings; these visually estimated intensities are made according to the usual practice of assigning values from 1 to 10 to the intensities of lines recorded on a plate. The following typical cases will serve to indicate the results which may be obtained by this instrument.

X-ray Diffraction Patterns: For the direct measurement of relative opacities in x-ray powder photographs the width of the lines is more than sufficient to cover the slit and the conditions are not exacting. A comparatively wide slit and a high speed of manipulation may therefore be used. In Figs. 3 and 4, are shown the curves obtained from powder photographs of pure sodium chloride and of corundum respectively; and below each curve is a copy of the powder photograph of the substance, enlarged to the same scale. These curves, and those which follow, have been inverted to make the peaks correspond to the spectrum lines. Because of the "normal decline" of intensities of the scattered radiation with distance from the undeviated beam the lowest points of the lines in these curves have not been reached. Defects in the films have produced false depressions and elevations in the curves.

Another application of the instrument to x-ray research is in the study of preferred orientation of crystals brought about by mechanical working of metals and the following of the accompanying changes in the physical properties. A single case will serve to illustrate: The upper curve in Fig. 5, is obtained from a diffraction pattern taken when the specimen of severely cold rolled steel is placed with the direction of rolling parallel to the width of the beam of x-rays; and the lower curve of Fig. 5 is given by a diffraction pattern of the same piece of



FIGS. 3, 4, and 5. *Curves and X-ray patterns.*

FIGS. 6, 7, and 8. *Curves and photographs.*

steel placed with the direction of rolling normal to the beam of x-rays. Between the two curves is a copy of the powder photographs taken on the same film.

Ordinary Spectra: By narrowing the slit it becomes possible to study the energy relations across spectral lines and to determine with considerable degree of accuracy the mean position of broad and diffuse lines which are so difficult of measurement by the usual methods. The speed of the motor is reduced in this work by inserting resistance in

series in order that the galvanometer deflections shall not lag behind the plate transmissions and the relative speed of drum to micrometer screw is increased four times to spread the intensity curve out.

Figs. 6, 7, and 8 indicate the applicability of the instrument to spectroscopy. Fig. 6 in the curve obtained from the potassium sharp doublet λ6911A and λ6639A, and it is evident that the symmetrical spectral lines yield symmetrical curves. Fig. 7 in the curve obtained from the potassium reversed doublet λ7665A and λ7699A. Fig. 8 is the curve obtained from the calcium composed triplet λ6439.09A–λ6508.84A. The curves are accompanied by copies of the spectra from which they were obtained. The relative intensities of the six lines in the calcium composed triplet have been quoted from King's estimates by Russell and Saunders.[8] If the second and third lines, which do not belong to this group, are excluded the intensities of the lines are: 150, 125, 40, 80, 30, 1 respectively. An inspection of the curve in Fig. 8 shows that those relative values are approximately those obtained with the densitometer.

PROPOSED USES FOR DENSITOMETER

This instrument should be of value in the x-ray estimation of amounts of constituents in a sample where chemical analysis will not give more than the "ultimate" compositions, *e.g.*, (a) in the detection of another phase or a metastable phase (as in nickel steel), and (b) in the tracing of the appearance or disappearance of this phase with treatment—as in heating for different periods of time at different temperatures. Preliminary work along this line has been performed by the Metallurgy Division.

Measurements of this kind should throw some light on the question of whether substituted "stranger" atoms in solid solutions of two metals belonging to the same crystal system (such as copper and gold) are, distributed in a regular manner or at random when rational compositions are used. If the distribution is regular, when a face-centered metal *A* is alloyed with a face-centered metal *B* in the proportion $1A:3B$ and allowed to reach equilibrium by annealing, a simple cubic pattern is obtained in addition to the face-centered cubic pattern because of the nature of the regular spacing of the "stranger" atoms. The introduction of the new lines, constituting with those of the original face-centered cubic pattern the simple cubic pattern, is accompanied by a reduction in the intensities of the face-centered cubic pattern. Measure-

[8] H. N. Russell and F. A. Saunders, Astrophysical J., *61*, p. 38; 1925.

ments of the relative intensities in the simple cubic pattern and the determination of the changes in the relative intensities when the composition is changed to $1A:1B$ or to $3A:1B$ can be carried on to advantage with the assistance rendered by the densitometer.

The effect of specimen-form on the relative intensities of the lines in x-ray diffraction patterns is not only of theoretical interest but it is of practical importance in the preparation of specimens for analysis. A study of the curves obtained from diffraction patterns of various forms of metal specimens should therefore prove valuable in choosing the best kind of specimen for specific types of information.

The densitometer will also be useful in studying the properties and crystal symmetry of certain compounds obtainable only in the powder form. More complete information is gained by using the densitometer than by using the eye for investigating the regions immediately adjacent to the strong lines in the powder photograph of the compound to ascertain if certain single lines are split up into two, three, or more components, or if the lines appear to be shifted sideways by various amounts.

The study of grain size vs. physical properties of a material, particularly as the grains approach colloidal dimensions, can be furthered by this densitometer. The observed width of a line in the powder photograph given by very minute crystals has been used by Scherrer[9] to estimate the size and internal structure of colloidal particles by means of x-rays. The lines in such cases are very diffuse; and since it is not possible to define precisely the absolute "width" of a diffuse line, it has been customary to put its width equal to the distance between points on each side of the line where the intensity has fallen to half that at the maximum. This method has already been used by Clark[10] in the study of nickel catalysts.

Instruments of this general type have recently found application in spectroscopy; they have been used to test the rules governing the relative intensities of lines in multiplets[11] and in Zeeman effect patterns,[12] to study the fine-structure of spectral lines,[13] and to compare intensities emitted from sources at different temperatures.[14] The photo-

[9] P. Scherrer, Nachr. Gesell. Wiss. Göttingen, 298; 1918.

[10] G. L. Clark, W. C. Ashbury, and R. M. Wick, J. Am. Chem. Soc., *47*, p. 2661; 1925.

[11] R. Frerichs, Ann. d. Phys., *81*, p. 807; 1926.

[12] L. S. Ornstein, H. C. Burger, and W. C. van Geel, ZS. f. Phys., *32*, p. 681; 1925.

[13] G. Hansen, Ann. d. Phys., *78*, p. 558; 1925.

[14] J. C. McLennan, H. G. Smith, & C. A. Lea, Proc. Roy. Soc., (London), *A113*, p. 183; 1926.

densitometer described in this paper can be used or adapted for use in these and similar spectroscopic problems.

SUMMARY

1. A self-registering photodensitometer has been described in which the direct-reading method and a thermocouple are employed.

2. The advantages of an improved optical system and a motive mechanism have been discussed.

3. Quick action and small lag of thermocouple-galvanometer system are obtained because of small heat capacity of thermocouple and special arrangement of galvanometer.

4. With this instrument is has been possible to study: (a) Relative intensities of lines in x-ray patterns of elements and of compounds. (b) Preferred orientation of crystals due to mechanical rolling. (c) Variation of intensity across wide spectrum lines and multiplets.

5. Several possible uses in x-ray research and in ordinary spectroscopy are pointed out.

The author is indebted to Mr. F. Sillers for drawing the diagram of the apparatus.

BIBLIOGRAPHY OF COLORIMETRY. In connection with the work of the Colorimetry Section of the Bureau of Standards and the report of the Colorimetry Committee of the Optical Society of America, I am desirous of compiling a bibliography of papers and books having direct bearing on colorimetry, spectrophotometry, and color specifications. It is expected that this bibliography will ultimately be published in the Journal of the Optical Society. It will also be of use in replying to frequent inquiries for information on this subject. In the interest of completeness and accuracy, all authors who have contributed to this subject are requested to send me check lists of their papers giving titles and complete journal references.

The following subjects are mentioned as illustrative of the classes of material desired:

1. Color of daylight and artificial sources. (Spectral distribution of energy, color temperature.)

2. Visual psychophysical data. (E.g. visibility of energy, hue discrimination, saturation discrimination, brilliance discrimination, excitations, abnormal color sense.)

3. Theories of color vision.

4. Methods of computing the trilinear coordinates, dominant wavelength, and purity, from data on spectral distribution.

5. Spectrophotometric instruments and methods.
6. Spectral transmission of materials.
7. Reflectance of materials.
8. Colorimeters.
9. Systems of color standards.
10. Applications of colorimetry and photometry to chemical analysis.
11. Turbidity and scattering of light.
12. Color nomenclature and terminology.

Reprints will also be of real service and will be gratefully received. I already have a considerable collection of such reprints. They are classified by subjects, and are of great assistance to those engaged in colorimetric research at the Bureau of Standards. This collection has been profitably used not only by regular members of the staff but by temporary research associates and visitors at the Bureau. It is desired to keep it up to date and make it as complete as possible. Authors who have reprints available can very effectively assist in the dissemination of information by contributing copies to this collection, since by consulting it workers on a given subject can find together in one place, the pertinent literature, the discovery of which would otherwise require diligent and laborious search through many scattered journals on physics, chemistry, psychology, physiology and sundry kinds of technology.

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A FLUORESCENT ULTRAVIOLET PHOTOMETER

By Wm. T. Anderson, Jr., and Elias Gordon

Recent years have seen a widespread employment of ultraviolet light in industry and medicine. With this increase has arisen a constantly increasing demand for a simple, practical and reasonably accurate method for measuring this form of energy. The laboratory methods for measuring ultraviolet are not at all practical for the physician who is desirous of knowing the intensity of his artificial light source in order to calculate dosage; nor is this equipment practical for the average industrial organization which employs ultraviolet energy. Very many different methods for measuring ultraviolet are at present in use, practically all of which depend on some form of chemical change. Thus, many substances decompose in ultraviolet radiation, the amount of decomposition being proportional to the intensity of the radiation. Many of these methods, if carefully performed, are very accurate. However, they require a certain amount of chemical skill and time for their operation, and consequently are suitable for only a few. The matching of faded dyes and darkened photographic paper to standard samples is another favorite method. These tests, however, are neither accurate nor dependable.

We have been studying, since 1924, methods available for measuring ultraviolet. While engaged in these studies it was found that fluorescence of certain substances excited by ultraviolet radiations can be matched by a variable comparison light source. This was in effect a fluorescent photometer which, after calibration, could serve as a simple and reasonably accurate means for measuring the intensity of ultraviolet light from a light source.

The light emitted by fluorescent substances is of such low intensity when compared to the light from lamps or natural daylight, that it is necessary to observe it in darkness or in dimmed illumination.

Since all practical methods for producing ultraviolet radiations also produce visible light it is necessary to enclose the fluorescent unit of the photometer in a light-tight container provided with a filter which transmits the exciting ultraviolet, but not the visible light from the light source. The best available filter is purple Corex, G986A. The ultraviolet transmission of this filter is shown in curve *B* of Fig. 1. In

addition to the ultraviolet it transmits a little of the violet, red and infrared. It is absolutely opaque to yellow and green light.

The most suitable fluorescent material for a practical photometer appears to be uranium glass; the curve *A* of Fig. 1 indicates the intensity of the fluorescent emission with exciting wave length. It is especially well adapted for use with the purple Corex for it responds to all the ultraviolet wave lengths transmitted by the Corex and emits in the yellow-green to which portion of the spectrum the Corex is completely opaque. This latter feature enables accurate observation of the fluorescent light.

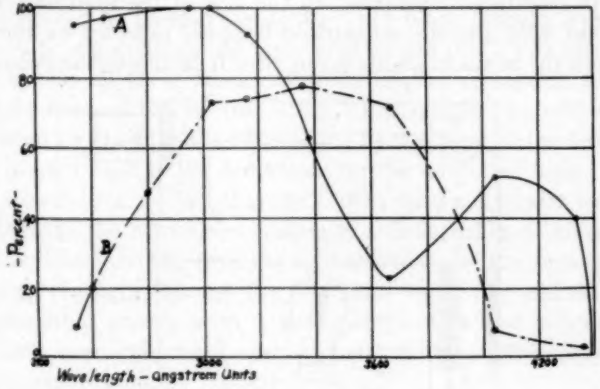

FIG. 1.

Curve A—Responsivity of uranium glass to exciting radiation in terms of maximum.
Curve B—Ultraviolet transmission of Corning G986A glass.

Variations in the transmission of the ultraviolet filter and in the responsivity of the uranium glass causes the intensity of the observed fluorescent light to be dependent not only on the intensity of the ultraviolet source but also upon the spectral distribution of the ultraviolet energy in the source. This latter necessitates that a photometer comprising these units, Corex filter and uranium glass, be calibrated against each type of light source with which it is to be employed.

Before entering into a discussion of calibration it is advisable to consider a practical form of fluorescent photometer such as is shown in Fig. 2. The photometer consists of a light-tight box. *A* is a movable disk in which there are cut a number of slit openings of uniform length and varying widths. By bringing the proper opening into position over the ultraviolet filter *B* it is possible to control the area of light incident

on the fluorescent uranium plate *C*. This area of light, as well as the intensity of the light, determines the brightness of the fluorescent light observed by the operator. These various slit openings enable the photometer to be used with a very much greater range of intensities than would otherwise be possible. Adjacent to the fluorescent plate and separated from it by an opaque partition *E* is a comparison plate of ground white glass *D* which is illuminated by a 110 volt incandescent bulb *G*, the intensity of which is controlled by a variable resistance (not shown in illustration) mounted on the meter box. The current consumption of the comparison lamp is indicated by a milliammeter (not shown in illustration) mounted on the side of the photometer. The fluorescent light and the comparison light are reflected by the mirror *F* through the monochromatic green filter *H*, and into the eye-piece *K*.

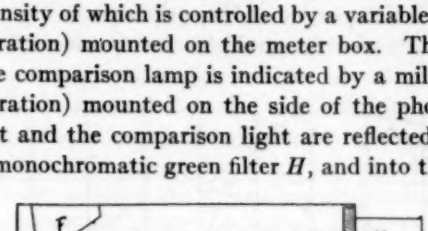

FIG. 2. *Special arrangement for fluorescent photometer.*

The calibration of this photometer is a very complicated procedure. It is necessary to measure the total ultraviolet from the light source falling on the slit of the photometer. This in itself is a problem for there is no filter available which transmits only the ultraviolet and 100 per cent of the ultraviolet. It was found possible to measure the total ultraviolet by a roundabout procedure which consisted of a determination of the spectral energy distribution of the ultraviolet of each light source, the determination of the relative intensity of the spectralized light through Corning G986A (purple Corex) glass, and a quartz water cell to absorb long infrared energy, and the measurement of the total light from the source through this filter and water cell and through the filter, water cell and Corning G24 red glass. Employing the data obtained from these measurements it is possible to calculate with considerable accuracy the total ultraviolet falling upon the slit of the

photometer. The procedure in detail was as follows:—the light from the source with which the meter was being calibrated was passed into a large corrected quartz prism monochromator, spectralized, and the radiations from 4100 to 2450 A.U. divided into 14 blocks of wave lengths. A portion of the visible violet is included because the ultraviolet filter transmits these wave lengths to a slight extent. Each one of these blocks of light was reduced to a definite area and projected on a Bi-Ag thermopile and galvanometer deflections noted. The sum of the galvanometer deflections for all the blocks represents the total intensity of the ultraviolet transmitted by the monochromator. The transmission of the G986A glass and the quartz water cell for each of these blocks was determined by passing the light of each block through it and then into the pile, maintaining the same area on the pile. The sum of the deflections for all these blocks of wave lengths represents the total ultraviolet transmitted by the filters. The relative amount of light transmitted by the filters is represented by the ratio of the deflections for the filtered light to the deflections for the unfiltered light.

If it were not for the fact that the G986A filter and quartz water cell in addition to the ultraviolet transmits a little red and infrared, the total ultraviolet intensity from the light source would now be determined by passing the light through the filter and water cell and measuring the transmitted energy with a Bi-Ag thermopile and galvanometer which have been calibrated against a standard radiation source, the following proportionality holding:

$$\frac{\text{Total intensity of 14 blocks}}{\text{Total intensity of 14 blocks through filter}} = \frac{\text{Total ultraviolet intensity of lamp}}{\text{Measured intensity of lamp through filters}}$$

It is necessary before the above proportionality can be employed to correct the "measured intensity of lamp through filters" for red and infrared light. This can be accomplished by interposing in addition to the ultraviolet filter and water cell a plate of red G24 Corning glass. This glass transmits only the red and infrared, and can be calibrated against the light source with which it is to be used.

Table 1 illustrates the determination of the total ultraviolet from a quartz mercury vapor arc lamp. It can be seen that when the preliminary measurements have been made the total ultraviolet intensity of the light source at any point may be rapidly determined by measuring the light passed through the G986A filter and the quartz water cell, and also through the filter, water cell and G24 glass. This latter value multiplied by the factor shown in the table corrects the component in-

tensity which may then be subtracted from the value of that through G986A filter and the water cell alone. The figure obtained in this way, and the other proper figures, are substituted in Equation 1 and the equation solved for total ultraviolet intensity of the light at the point

TABLE 1. *Total ultraviolet from quartz mercury arc at a distance of 40".*
(Old lamp, operating at 75 volts, 3.5 amps.)

Block of wavelengths-Angstrom units	Distribution of energy in mm deflec.	Percentage distribution	Distribution through filters	Percentage transmission through filter, G986A, & water cell	Ergs/per sec/ per mm² at 40"
4100–4000	161	10.8	11	7	2.84
4000–3800	8	0.5	4	50	0.13
3800–3600	442	29.8	263	60	7.83
3600–3200	44	2.9	28	64	0.76
3200–3100	282	19.0	172	61	4.99
3100–3000	136	9.1	76	56	2.39
3000–2950	57	3.8	30	53	1.00
2950–2900	30	2.0	13	43	0.53
2900–2780	51	3.4	19	37	0.90
2780–2720	18	1.2	6	33	0.31
2720–2680	27	1.8	6	22	0.47
2680–2600	94	6.3	11	12	1.65
2600–2520	97	6.5	3	3	1.71
2520–2450	36	2.4	1	3	0.63
4100–2450	1483*	100.	643	44.5	26.29

* Totals are what they should be, not the actual addition values.

Total Intensity of 14 blocks = 1483 mm defl.
" " " 14 " through filters = 643 " "
Measured Intensity of lamp through filters = 94 " "
" " " " through filters and G24 = 2 " "
Infrared factor = 1.32; 1.32×2= (approximately 3 " "
94−3=91, ultraviolet energy

$$\frac{1483}{643}=\frac{X}{91};\quad X=212 \text{ mm defl., total ultraviolet energy at } 40"$$

By Calibration against standard lamp, 1 mm defl. is equivalent to 0.124 ergs/per sec./per mm².
212×0.124=26.29 ergs/per sec./per mm²

at which the measurements were made. If then the photometer slit is placed in the position formerly occupied by the thermopile and the filter and water cell are removed, other conditions remaining unchanged, a slit opening and reading of the milliammeter will be found which cor-

responds to the particular light intensity. These measurements must be repeated through a whole range of intensities so that every slit in the disk is employed a number of times, with a number of readings on the milliammeter. The instrument is then calibrated against the particular light source and the calibration may be such that the milliammeter readings for a particular slit are immediately converted into absolute units, ergs/per sec./per mm² by reference to a table. When once calibrated in this way the meter may be employed for measuring the intensity of the ultraviolet light from all sources of this type. In order to be employed with other types of sources it must be calibrated against them in the manner described above.

If every photometer had to be calibrated in this manner it would be entirely impractical to make any quantity of these instruments.

FIG. 3. *Fluorescent photometer in practice*

Fortunately, however, it is possible to calibrate a standard instrument and refer other instruments to this standard.

It is obvious that the method of calibration as above adopted eliminates any variability introduced because of the unequal transmission of the ultraviolet filter and the variable responsivity of the uranium glass. In a similar way variations in the composition of the various batches of the glasses will in no way affect the accuracy of the meters.

The photometer is of special value to the physician who wishes to measure the intensity of his ultraviolet lamp each time a treatment is

given, for, after a little experience, a measurement can be made and checked within less than a minute. Its use also enables him to increase or decrease the intensity of treatment by altering the distance.

It should be pointed out that this apparatus measures only the quantity of ultraviolet, not the wave lengths. It can be made to operate just as satisfactorily with the long ultraviolet from the sun as with the quartz mercury vapor arc lamp. It is believed that with the aid of a device such as this the user of ultraviolet will be able to keep a better check on the amount of energy he is obtaining.

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Photography, Its Principles and Applications.—Alfred Watkins. (Revised third edition.) Pp. xvi+336. D. VanNostrand Company. $4.00, 1927.

The first edition of this well written and well made book appeared in 1911. The author, then a photographer of forty years' standing who had done a great deal in the working out of methods in exposure and plate development, addressed himself to "the beginner who wishes to master photography" as an art and a science. He produced a handy volume, full of information that the professional photographer needs and the ambitious amateur wants.

The present-day acceptance of the "press the button, we do the rest" suggestion has caused such beginners and amateurs largely to disappear. In this edition of the book the author voices regret over the result,—"a slackened rate in real advance and poorer public standards in results, coinciding with the decay of the amateur craftsman and the advent of the camera user."

The new volume contains new illustrations substituted for those of apparatus now obsolete; also new chapters on aeroplane photography and on cinematograph photography, which is now coming within the "press the button" reach of everybody. That it is not too technical for popular reading is shown by such remarks as, "A light ray, palpitating with hidden power . . . . ." A reference to "the accepted theory" of color vision is evidently carried over from the first edition without revision.

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